ANALOG TECHNOLOGIES, INC. · APPLICATION WHITE PAPER

Thermoelectric Cooler (TEC) vs. Thermoelectric Generator (TEG)

How Peltier and Seebeck devices work, how they differ, and how to select and control TEC modules, TEC controllers, and TEG modules — including high-temperature and long-life TEC families.

A complete engineering reference: thermoelectric theory and the figure of merit ZT, the coefficient of performance (COP), the heat-pump and power-generation design equations, closed-loop temperature control, module reliability, and a practical three-gate method for selecting ATI TEC modules, TEC controllers, and TEG modules.

Document: AWTMTG-05 · Rev. H · **Date:** June 2026 · **Primary keyword:** thermoelectric cooler vs thermoelectric generator

Audience: Design, electrical, optical, and mechanical engineers; system architects; researchers; technical managers; purchasing professionals.

> **DIRECT ANSWER**
>
> A TEC uses electrical current to pump heat by the Peltier effect for controlled heating or cooling; a TEG uses a temperature difference to generate electrical power by the Seebeck effect. Choose an ATI high-temperature –H TEC when the hot-side or surface temperature can exceed regular limits, and an ATI long-life ATE1-TC / ATE1-TCHE module when repeated full-current reversal makes fatigue and ACR rise the dominant risk.

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Replaces the legacy note “The Difference Between TEC and TEG.” Operating under an ISO-9001 quality system.

Contents

Document at a glance.

This paper answers three questions: what a TEC and a TEG each do and why they are reciprocal; how to size a cooler and its hot side from the governing equations; and how to pass the three selection gates onto the correct ATI family. To skip to selection, see Section 8 (the gates), Section 13 (the product map), or the Quick-Reference Card. See also the ATI white-paper library.

FAST ROUTES

Need a decision, not theory? Jump straight in: size and pick a Peltier cooling element (§8 gates & §13 map), choose a bipolar controller (§6), or evaluate a TEG harvesting opportunity (§11). Designers who prefer first principles can read straight through from Section 3.

1. Executive Summary

DIRECT ANSWER

> A thermoelectric cooler (TEC, or Peltier module) is a solid-state heat pump that spends electrical current to move heat across a semiconductor junction. A thermoelectric generator (TEG) is the reciprocal device that spends a temperature difference to produce DC electrical power by the Seebeck effect.

TEC and TEG modules look almost identical — flat ceramic plates a few millimeters thick with two lead wires — but they are optimized for opposite directions of energy flow. One buys temperature control with watts; the other sells a temperature difference for watts.

The TEC selection decision has three gates. This paper treats them as first-order engineering requirements, equal in weight to Qc, ΔT, Imax, and Vmax:

- **Thermal capacity** — can the module pump the required cold-side heat at the real ΔT?
- **Temperature class** — can the module's solder system and package survive the hot-side, ceramic-surface, or process temperature?
- **Cycling lifetime** — can the module survive the number of full-scale current reversals expected over the product life?

ATI's product families map cleanly onto these gates: Regular Temperature bismuth-telluride coolers for ordinary precision cooling, High-Temperature –H TECs for hot environments up to 200 °C, and ATE1-TC / ATE1-TCHE long-life TECs for repeated thermal cycling up to the published 20,000-reversal ACR criterion.

Five takeaways to keep in your head

- **TEC = heat pump driven by electricity.** Apply DC current; one face cools, the other heats. Reverse the current and the faces swap — ideal for precise temperature control of lasers, detectors, and instruments with an ATI solid-state heat pump.
- **TEG = generator driven by heat.** Apply a temperature difference and an ATI TEG module sources DC voltage and current into a load — ideal for harvesting waste heat into usable power.
- **Same physics, reciprocal use.** Both rely on the Peltier and Seebeck effects in bismuth-telluride couples; geometry and fill factor are tuned for either cooling COP or generation efficiency.
- **A TEC is only as good as its controller and heat sink.** Cooling collapses if hot-side heat is not removed; stability depends on a bipolar, current-limited closed-loop controller and a well-placed sensor.
- **Not all TECs are the same.** In hot ambients or high-reversal duty, a Regular Temperature module is the wrong choice — ATI offers high-temperature and long-life families engineered for exactly those conditions (Section 8).

2. Introduction

Thermoelectric devices are prized because they have no moving parts, no working fluid, and no sound. A Peltier cooling element can hold a laser diode or photodetector to within thousandths of a degree; a Seebeck generator can quietly turn the heat of an engine exhaust or a remote gas pipeline into electricity for sensors. Both are built from the same semiconductor couples, which is exactly why they are so often confused.

The distinction matters because choosing the wrong device — or the wrong supporting electronics — is a common and expensive mistake. Driving a cooling-optimized module as a generator wastes most of its potential; sizing a TEC without budgeting hot-side heat removal guarantees the target temperature is never reached; regulating a Peltier element with a unipolar supply throws away half its capability; and specifying a Regular Temperature module for a 150 °C ambient or a high-cycling PCR block invites early failure — the kind that turns a prototype into a small, expensive hand warmer with a purchase-order number.

2.1 How to use this document

- Sections 3–5 explain the physics, the governing equations, and the head-to-head TEC/TEG comparison.
- Sections 6–10 cover closed-loop control, the design procedure, the three-gate selection method, reliability, and a worked sizing example.
- Sections 11–17 provide TEG evaluation, applications, ATI product selection, best practices, troubleshooting, and an FAQ — followed by a one-page Quick-Reference Card.

3. Technical Background: The Thermoelectric Effects

Four physical effects govern every thermoelectric device. Two are useful and reversible (Peltier and Seebeck); two are parasitic and irreversible (Joule heating and Fourier conduction). Good design maximizes the first pair and minimizes the second.

Effect	What it does	Role in TEC / TEG
Peltier	Current across a junction of two dissimilar materials absorbs or releases heat	The cooling mechanism of a TEC — heat is pumped from the cold face to the hot face
Seebeck	A temperature difference across a junction produces a voltage	The generating mechanism of a TEG — and the basis of thermocouple feedback
Thomson	Heat absorbed or released when current flows along a thermal gradient	A second-order correction in precise modeling
Joule	I^2R heating in the element resistance (irreversible)	Parasitic; about half returns to the cold side, limiting net cooling
Fourier	Heat conducts back from the hot to the cold face down the gradient	Parasitic; sets the maximum achievable ΔT

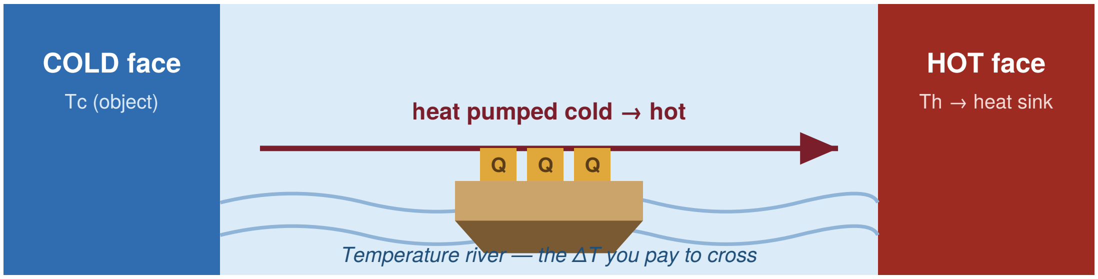
Table 3-1. The four (plus Thomson) thermoelectric effects. A TEC exploits Peltier; a TEG exploits Seebeck; Joule and Fourier limit both.

A practical module contains many thermocouples — pairs of N-type and P-type bismuth-telluride (Bi_2Te_3) pellets — connected electrically in series and thermally in parallel between two ceramic plates (typically alumina). The series electrical connection lets a modest current develop useful pumping across all couples; the thermal parallel connection spreads the heat across the full ceramic face. ATI organizes its thermoelectric cooler modules by couple count, from roughly 7 to 288 couples, and by form factor and family (rectangular and circular TECs, high-temperature, and long-life). This shared construction is exactly why a TEC and a TEG can look identical while being tuned for opposite tasks.

> **Memory hook: a TEC is a metered heat ferry.**
>
> Temperature is the "voltage" of the thermal world, heat flow is the "current," and thermal resistance is the "resistance": $\Delta T = Q \times R\theta$, the thermal twin of Ohm's law $V = I \times R$. A TEC is the ferry that charges you in watts for every watt of thermal cargo it carries across the temperature river; a TEG is the same ferry running

> downhill, selling you a ticket on the way. And a handsome heat sink with poor airflow? Just a shiny resistor with the wrong value.

Cartoon 3-1 · The metered heat ferry



Fare: Pin watts in → Qh = Qc + Pin out
(every crate also pays an I^2R surcharge)

Cartoon 3-1. A TEC ferries heat from the cold object to the hot face; you pay the fare in watts (Pin), and the hot side must unload everything — Qh = Qc + Pin. Cut the airflow at the dock and the ferry backs up.

3.1 TEC: the Peltier heat pump

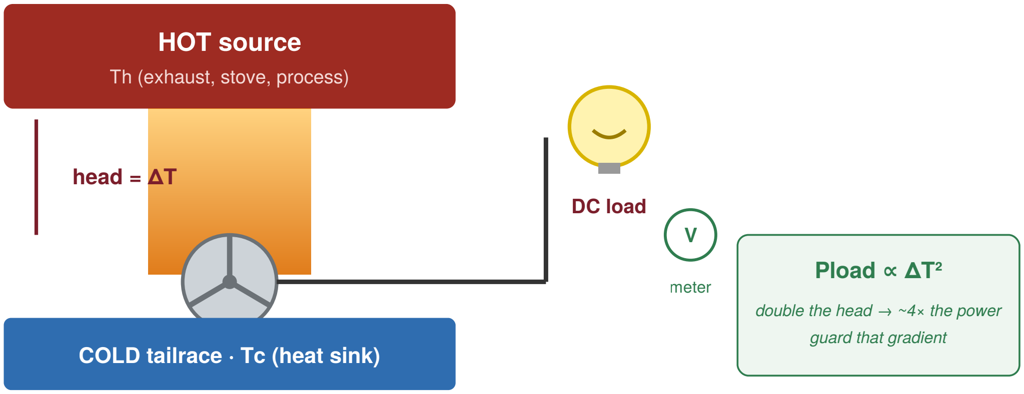
When DC current flows through the couples, the Peltier effect carries heat from one ceramic face (which becomes cold) to the other (which becomes hot). Reversing the current polarity reverses the heat-flow direction, so a single Peltier module can both cool and heat — the property that lets bipolar TEC controllers hold a setpoint against ambient swings in either direction.

3.2 TEG: the Seebeck generator

If, instead of driving current, you impose a temperature difference across the module faces, the Seebeck effect produces an electromotive force and the module delivers DC power to a load. This is the operating mode of an ATI TEG module, used to convert waste heat — from exhausts, stoves, industrial processes, or radioisotope sources — directly into electricity for instrumentation and remote power. A useful mental image is a hydroelectric dam: a hot upper reservoir and a cold tailrace separated by a “head” (the ΔT). Let heat fall through that head and the turbine delivers power — and because power scales with the square of the head, a bigger ΔT yields disproportionately more output.

> **Reading the waterfall.**
>
> The single most important design move in a Seebeck generator is to protect the gradient. Because matched-load power follows ΔT^2, every degree lost to a poor interface or a weak cold-side sink is paid back roughly squared in lost watts — so flat, well-clamped contact surfaces and a generous heat exchanger matter as much as the module itself. Keep the head high and the contact resistance low, and an ATI TEG module returns disproportionately more power.

Cartoon 3-2 · The thermoelectric generator as a waterfall



Cartoon 3-2. A TEG sells a temperature difference for watts. Voltage rises roughly with ΔT, but matched-load power rises with ΔT² — so contact resistance and a weak sink quietly steal most of the output.

4. Fundamental Theory: ZT, COP, and Governing Equations

4.1 The figure of merit, ZT

The intrinsic quality of a thermoelectric material is captured by the dimensionless figure of merit:

$$ZT = (S^2 \cdot \sigma / k) \cdot T = (S^2 / (\rho \cdot k)) \cdot T$$

where S is the Seebeck coefficient (V/K), σ is electrical conductivity (ρ is resistivity), k is thermal conductivity, and T is absolute temperature. A good thermoelectric material wants a high Seebeck coefficient, high electrical conductivity, and low thermal conductivity simultaneously — a difficult combination, since those properties are physically linked. Commercial bismuth-telluride coolers achieve ZT ≈ 0.8–1.1 near room temperature. ZT bounds both the maximum temperature drop a TEC module can produce and the maximum conversion efficiency of a TEG.

4.2 TEC cooling equations

The net heat absorbed at the cold side is the Peltier pumping minus half the Joule heat minus the Fourier back-conduction:

$$Qc = S \cdot I \cdot Tc - \tfrac{1}{2} \cdot I^2 \cdot R - K \cdot \Delta T$$

where Qc is the cold-side heat absorbed (the useful cooling), I is the drive current, Tc is the cold-side absolute temperature, R is the module electrical resistance, K is the thermal conductance, and ΔT = Th − Tc. The electrical power the supply must provide is the pumped heat plus the Joule loss; the hot side must reject the sum of both:

$$Pin = S \cdot I \cdot \Delta T + I^2 \cdot R \qquad Qh = Qc + Pin$$

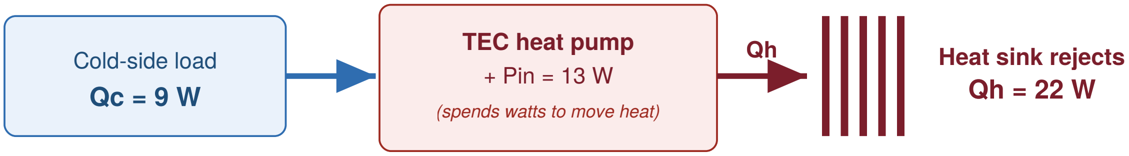
The coefficient of performance — cooling delivered per watt of electrical input — is therefore:

$$COP = Q_c / P_{in}$$

ATI TEC controllers automatically optimize COP by limiting drive current to roughly 70% of Imax, the point at which added Joule heat begins to overwhelm added Peltier pumping.

> **Why hot-side heat removal is non-negotiable.**
> The hot side must dissipate Qh = Qc + Pin — always more heat than the TEC removes from the cold side, because the input electrical power is added to the pumped heat. A TEC that pumps 20 W of cooling while drawing 30 W must reject 50 W at the hot face. If the heat sink cannot remove 50 W, the hot side heats up, ΔT rises, and cold-side cooling collapses. Heat-sink design is part of TEC design, not an afterthought.

The hot side must reject everything: Qh = Qc + Pin



Size the sink for 22 W, not 9 W — a marginal sink makes a correct module fail.

Figure 4-1. The hot side must reject the cold-side load plus the electrical input power, not just the cooling load.

4.3 Maximum temperature difference

Setting Qc = 0 (no cooling load) gives the largest temperature drop a module can reach, the catalog parameter ΔTmax, which for single-stage bismuth-telluride modules is roughly 65–75 K at room temperature. Achieving large ΔT and high cooling power simultaneously is impossible; multistage (cascade) modules trade efficiency for greater ΔT. Because COP improves as ΔT falls, ATI recommends keeping ΔT below about 30 °C wherever the system allows, for efficient operation. Confirm Qcmax, ΔTmax, Imax, and Vmax for a candidate part on the relevant ATI single-stage TEC page.

4.4 TEG generation equations

Operating in reverse, an open-circuit temperature difference produces a Seebeck voltage; under load the module delivers power, maximized when the load resistance matches the module resistance. Browse ATI TEG modules with published Seebeck behavior:

$$V_{oc} = S \cdot \Delta T \qquad P_{load,max} = (S \cdot \Delta T)^2 / (4R) \quad \text{at} \quad R_{load} = R_{module}$$

Because TEG voltage rises approximately linearly with ΔT while matched-load power rises approximately with ΔT^2, small improvements in thermal contact and heat-sink performance produce large improvements in usable power — and, conversely, halving the true ΔT can cut available matched-load power roughly fourfold. TEG conversion efficiency rises with ΔT and with ZT but remains modest (typically a few percent up to about 8%), which is why TEGs target waste heat that would otherwise be lost.

5. TEC vs. TEG: Direct Comparison

DIRECT ANSWER

A TEC controls temperature; a TEG harvests energy. The two devices share construction and materials but are specified, driven, and selected very differently.

Attribute	TEC (Peltier cooler)	TEG (Seebeck generator)
Energy direction	Electricity → heat movement	Heat → electricity
Driving input	DC current from a TEC controller	Temperature difference across faces
Useful output	Cooling (and heating) of a controlled surface	DC electrical power into a load
Governing effect	Peltier	Seebeck
Polarity behavior	Reversing current swaps hot/cold — cools or heats	Reversing ΔT reverses output polarity
Key spec	Qcmax, ΔTmax, Imax, Vmax, COP	Power at rated ΔT, matched-load R, open-circuit V
Reliability class to check	Temperature class, cycling lifetime, ACR trend, hot-side margin	Hot/cold limits, clamping, thermal interface, load match
ATI product path	TEC modules + TEC controllers	TEG modules

Table 5-1. Practical comparison of thermoelectric coolers and generators.

DIRECT ANSWER

Can one module do both? Physically yes — the effects are reciprocal, so a TEC can generate a small voltage from a temperature difference and a TEG can pump a little heat from current. But a module optimized for cooling COP is not optimized for generation efficiency, and vice versa. For production designs, use a TEC module for cooling and temperature control and a TEG module for power generation; do not substitute one for the other.

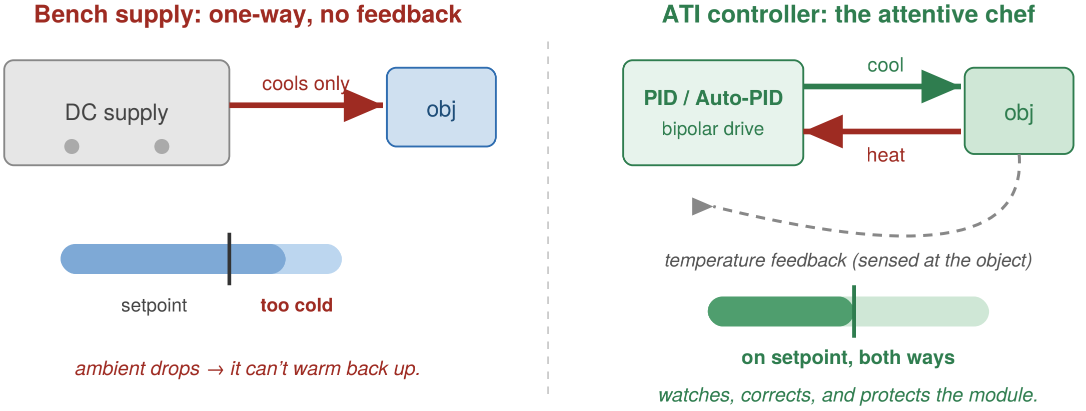
6. System Architecture: Closed-Loop TEC Control

DIRECT ANSWER

A bare DC supply can make one face hot and the other cold, but it cannot regulate an object against changing ambient, load, or airflow. Precise control needs a closed loop: a sensor, a controller, and a bipolar current driver. ATI TEC controllers regulate temperature by controlling both the direction and the amplitude of current through the TEC.

A plain bench supply pushes current in one direction and hopes for the best: it has no feedback, cools only, drifts when the ambient moves, and cannot warm an object back up. An ATI TEC/Peltier controller watches the object, computes the error against the setpoint, and pushes — or pulls — exactly as much current as the setpoint needs, holding regulation in both directions.

Cartoon 6-1 · Bench supply vs. TEC controller



Cartoon 6-1. A bench supply is a stubborn line cook who only knows "colder" and never tastes the dish. A TEC controller is the chef who watches the thermometer and adjusts heat or cooling in real time — which is why bipolar, closed-loop control holds a setpoint that a supply cannot.

Signal chain

- **Temperature sensor.** A precision NTC thermistor (or RTD/IC sensor) bonded near the controlled object reports the actual temperature. A sensor placed on the heat sink may read beautifully stable while the laser submount drifts.
- **Error amplifier / PID.** The ATI TEC controller computes the error between setpoint and measurement and applies proportional-integral-derivative compensation for fast, stable settling without overshoot. Auto-PID firmware can remove manual loop tuning entirely.
- **Bipolar output stage.** A four-quadrant (H-bridge or linear) driver sources current in either polarity so the TEC can both cool and heat, with programmable current and voltage limits to protect the module.
- **TEC module + thermal load.** The Peltier cooling element pumps heat between the controlled object and the hot-side heat sink, closing the physical loop.

Closed-loop TEC control signal chain

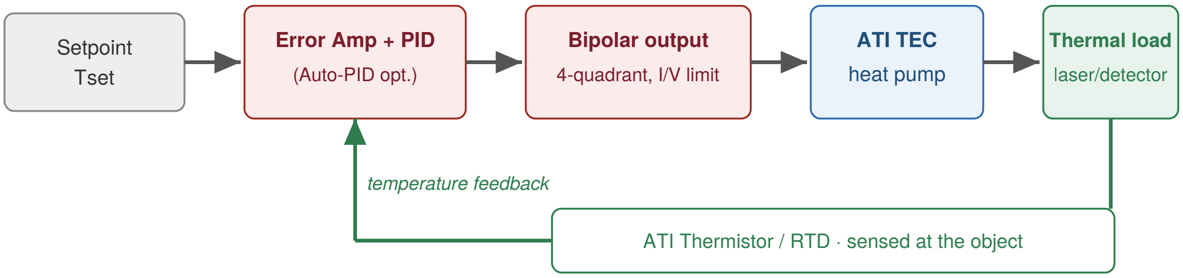


Figure 6-1. Closed-loop TEC control: the error amplifier and bipolar output stage form the controller; the sensor reads the object, not the heat sink.

Why bipolar control matters.

> A unipolar driver can only cool. If the ambient drops below the setpoint, a cool-only system cannot warm the object back up and loses regulation. A bipolar TEC controller actively heats or cools as needed, holding the setpoint against ambient changes in both directions — essential for laser-wavelength stability and for instruments that must hold temperature in a varying environment. ATI controllers provide bipolar drive with current limiting to protect the module.

> **DIRECT ANSWER**
>
> Linear or PWM drive? Linear output stages produce the lowest electrical noise — choose them when the load is noise-sensitive (low-noise laser and sensor systems). Choose switching (PWM) output stages when efficiency at high power matters more than noise. It is a noise-versus-efficiency tradeoff (Section 9); both are available in ATI TEC/Peltier controllers.

ATI’s TEC controllers use a patented single-PWM-engine output stage (U.S. Patent 6,486,643 B2) stated to cut power loss by about 20%, component cost by about 25%, and PCB component area by about 35% versus conventional two-PWM-engine designs — addressing heat, size, and cost simultaneously. For larger modules, step up to a high-current TEC controller.

> **★ ATI Exclusive: Auto-PID Compensation**
>
> Traditional TEC controllers require manual tuning of the PID compensation network to match each thermal load. Get it slightly wrong and temperature stability degrades or the loop hunts. ATI’s Auto-PID controller automatically tunes the compensation network, eliminating manual adjustment and holding optimal stability regardless of the thermal-load characteristics — believed to be the world’s first such controller. If you have ever spent an afternoon nudging gain and time-constant pots, this is the feature you will tell a colleague about.

> **★ ATI Exclusive: Fully Shielded, Zero-EMI Controllers**
>
> Every ATI TEC/Peltier controller is fully shielded for effectively zero radiated EMI. For engineers stabilizing a narrow-linewidth laser, a sensitive photodetector, or an RF front end, a controller that does not spray switching noise into the signal path is not a luxury — it is the difference between a clean measurement and chasing a phantom spur. Pair a shielded linear-output controller with a precision thermistor for the quietest possible loop.

7. Design Considerations & Procedure

The design procedure should begin with the load, not with a catalog part number. Define the controlled-object temperature, ambient range, steady and transient heat loads, package size, and mounting method first; then work toward the module, heat sink, controller, and sensor.

Step	Design action	Why it matters
1	Quantify Qc: active dissipation plus parasitic leaks (conduction, convection, radiation, wiring).	The TEC module must remove all cold-side heat, not just nominal device power.
2		

Step	Design action	Why it matters
	Define the required ΔT = hot-side temperature (ambient + sink rise) minus the cold-side target.	TEC capacity depends strongly on ΔT; a better heat sink lowers demand.
3	Select a module from the datasheet Qc–ΔT curves so the operating point sits below Qcmax and ΔTmax.	Match the cooler to the working point — Qmax at ΔT = 0 is not the working capacity.
4	Budget the hot-side heat sink for Qh = Qc + Pin, not just Qc.	Heat rejected at the hot side exceeds the cold-side load; size the sink accordingly.
5	Choose the controller: I/V limits at or above the module's Imax/Vmax, bipolar drive, correct sensor interface, stability class.	Loop performance is limited by the controller and the thermal dynamics together.
6	Review mounting, compression, insulation, sensor placement, and condensation control.	Many field failures are mechanical or environmental; place the sensor at the object.
7	Verify on hardware.	Interface quality and real airflow dominate the final margin; ATI engineering can review your operating point.

Table 7-1. Recommended TEC sizing workflow (a seven-step how-to procedure).

> **DIRECT ANSWER**
>
> How do I size a heat sink for a TEC? Size the hot-side sink for Qh = Qc + Pin — the cold-side load plus the electrical input power — never for Qc alone. Pick the thermal resistance Rθ so that Qh × Rθ keeps the hot-side rise within your ΔT budget at the worst-case ambient. A sink sized only for the cooling load will let the hot face climb, ΔT rise, and cooling collapse. See ATI heat sinks and thermal components.

7.1 Setting current and voltage limits

Never drive a TEC beyond its rated Imax/Vmax. Beyond Imax, added Joule heat overwhelms added Peltier pumping and cooling actually decreases. Program the controller's limits from the module datasheet; a properly limited TEC controller protects the module across all operating conditions. Note that both usable cooling capacity and COP fall as ΔT rises — keep the operating point in the low-ΔT region wherever the system allows.

> **Pro tip from the bench.**
>
> If your TEC is running above about 70% of Imax, you are mostly buying Joule heat, not cooling. Back the current limit down toward 50% and, if you still need more ΔT, reach for a larger module or a second stage before you reach for more amps. Your COP — and your hot-side sink — will thank you.

7.2 Mounting, interface, and sensor placement

- **Flatness and thermal interface.** Mount the module between flat, lapped surfaces with a thin, even layer of thermal interface material; uneven mounting causes hot spots and mechanical stress.
- **Even clamping pressure.** Apply the manufacturer-specified compression uniformly; the ceramic is brittle and intolerant of bending and shear.
- **Sensor location.** Place the sensor as close as possible to the controlled object, not on the module case, to minimize thermal lag and steady-state error.

- **Condensation control.** When cooling below the dew point, seal and, if needed, dry-gas-purge the cold zone to prevent condensation and ice.

8. The Three-Gate Selection Method: High-Temperature and Long-Life TEC Families

> **DIRECT ANSWER**
>
> Gate 1 is thermal capacity (covered in Sections 4 and 7). Gates 2 and 3 — temperature class and cycling lifetime — are where Regular Temperature modules silently fail. Selecting the right TEC family early prevents the most expensive class of TEC failure, the kind that only appears after months in the field.

Every design must pass three gates in order. Most engineers guard only Gate 1 (capacity); Gates 2 and 3 are where Regular Temperature modules are turned away. Gate 2 routes hot environments to the High-Temperature –H family, and Gate 3 routes high-reversal duty to the long-life ATE1-TC / ATE1-TCHE family — families a capacity-only search would never surface. Pass all three and you reach the correct ATI family.

The three-gate decision tree

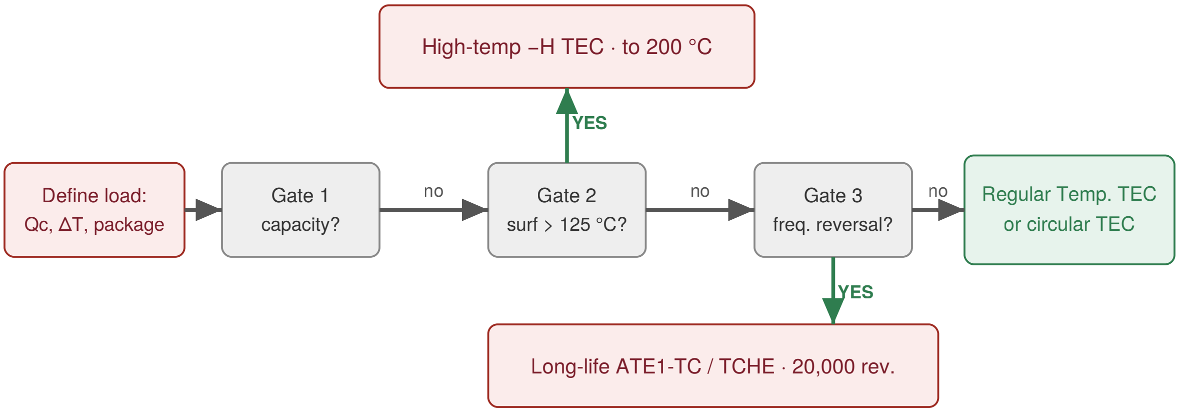


Figure 8-1. The three-gate decision tree. Gate 2 routes hot environments to –H TECs; Gate 3 routes high-reversal duty to long-life ATE1-TC / TCHE modules.

8.1 Gate 2 — Temperature class: when the ambient itself is the hazard

A Regular Temperature TEC module is built with internal solder rated near 135 °C and carries a maximum surface temperature around 125 °C. In a hot enclosure, a furnace-adjacent instrument, downhole equipment, or an engine bay, that surface limit — not the electrical design — becomes the binding constraint, and a Regular Temperature module simply cannot survive there. ATI's High-Temperature –H TECs use internal solder rated near 238 °C and are rated for operation up to 200 °C, roughly a 75 °C extension of the usable envelope.

> **When to specify a high-temperature TEC.**
>
> Choose a high-temperature –H module whenever the hot-side or ambient temperature can approach or exceed the ~125 °C surface limit of a Regular Temperature module — high-ambient industrial cooling, process equipment, automotive and aerospace bays, and sealed enclosures with limited convection. The

> design review must ask: what is the worst credible hot-side or ceramic-surface temperature during startup, fault, blocked airflow, high ambient, cleaning cycle, or service condition? If the answer approaches the regular limit, the −H family deserves early review. Confirm exact limits against the current ATI datasheet.

8.2 Gate 3 — Cycling lifetime: when the duty cycle is the hazard

The dominant wear-out mechanism in a TEC is thermal-cycling fatigue of the internal solder joints: every full-scale current reversal expands and contracts the pellets and conductors, and micro-cracks accumulate until the module's AC resistance (ACR) rises and cooling degrades. ATI defines a 10% rise in ACR as the end of useful life. The contrast between module classes is dramatic: a Regular Temperature module reaches the threshold in roughly 500–1,000 reversals, while a long-life ATE1-TC / ATE1-TCHE module reaches the same point near 20,000 — about 20× the endurance.

TEC class	Reversals to 10% ACR rise	Best fit
Regular Temperature TEC module	≈ 500–1,000 reversals	Steady-state cooling, infrequent polarity changes
Long-life thermal-cycling (ATE1-TC)	up to 20,000 reversals	PCR/qPCR blocks, repeated heat/cool cycling
Long-life high-efficiency (ATE1-TCHE)	up to 20,000 reversals	High-cycling duty where COP also matters

Table 8-1. Regular Temperature vs. long-life thermal-cycling TECs. A long-life series delivers roughly 20× the cycling endurance. Confirm ratings against the current ATI datasheet.

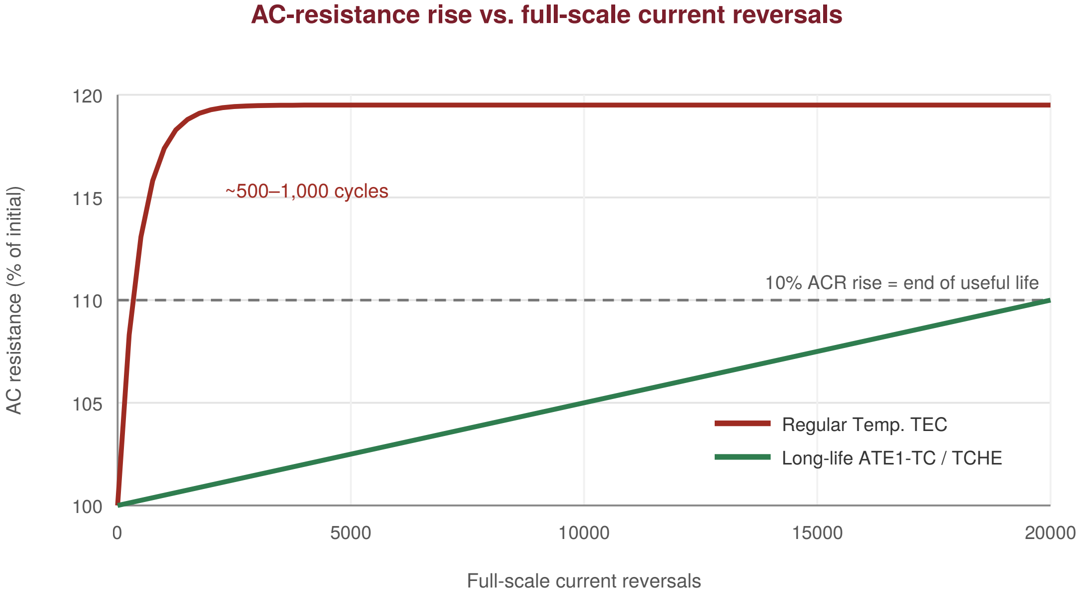


Figure 8-2. AC-resistance rise under repeated full-scale current reversal (illustrative; confirm against current ATI datasheets). The long-life family reaches the 10% end-of-life threshold near 20,000 reversals — about 20× the endurance.

A Regular Temperature module used in a thermal cycler may reach end of life in a few thousand cycles — sometimes within weeks of continuous operation — while a long-life ATE1-TC or ATE1-TCHE module is engineered to absorb roughly twenty times the cycling before the same 10% ACR threshold is reached. For any application that reverses current frequently to heat and then cool, the long-life family is not a premium upgrade; it is the correct part.

Reliability practice: measure ACR, not DC resistance.

ACR is the meaningful life indicator because it reveals micro-cracking that a DC measurement hides. Measure it with a proper LCR meter — an ordinary multimeter reads DC resistance and will not expose the same failure information. Pre-screening ACR at incoming inspection and trending it in service is an inexpensive way to catch a fatiguing or shock-damaged module before it fails in the field.

8.3 Choosing by the first dominant operating stress

Check the special stress conditions first; then optimize Qc, ΔT, controller, sensor, and heat sink.

Dominant stress	Wrong shortcut	Better ATI-oriented decision	Why it is safer
Hot side or ceramic surface may exceed 125 °C	Use a regular TEC because Qmax looks adequate	Review ATI high-temperature –H TECs	Temperature rating and solder system must survive the real surface temperature
PCR, thermal cycling, or frequent full-current reversal	Use a Regular Temperature TEC and hope the duty cycle is gentle	Review ATI ATE1-TC / ATE1-TCHE long-life TECs	Reversal fatigue shows up as ACR rise; long-life families publish up to 20,000 reversals
Optical package with central beam path	Force a Regular Temperature module into a circular optical problem	Review ATI circular TEC modules	Geometry and optical clearance can be the controlling requirement
Ordinary steady precision cooling	Buy the largest TEC that fits	Select by Qc at the actual ΔT, Imax, Vmax, package, controller, heat-sink margin	Oversized TECs increase current, heat rejection, and control difficulty

Table 8-2. ATI TEC family selection by the first dominant operating stress. Product names link to the relevant ATI family page.

9. Engineering Challenges, Tradeoffs & Reliability

9.1 Key tradeoffs

- **ΔT vs. cooling power.** A Peltier cooling element cannot deliver maximum ΔT and maximum Qc at once; pick the operating point for the actual load.
- **COP vs. drive current.** COP falls as current rises toward Imax; running gently (lower current via the controller, a larger module) saves input power and hot-side heat.
- **Linear vs. PWM drive.** Linear gives the lowest noise; PWM gives the highest efficiency. Choose your controller output stage by whether the load is noise-sensitive.
- **Single-stage vs. multistage.** Cascade modules reach larger ΔT but at lower COP and higher cost.
- **Regular vs. high-temperature / long-life.** Specialized families cost more per unit but are the only correct choice in hot or high-cycling service (Section 8).

From the lab bench — a $40,000 lesson.

A customer once shipped a fluorescence reader with a perfectly sized Regular Temperature module driving a small reaction block. It passed every bench test. Six weeks into a customer's lab it stopped cooling — the

> block was reversing current dozens of times an hour and the solder joints had fatigued past the 10% ACR line. An ATI ATE1-TCHE long-life, high-temperature module — rated for up to 20,000 full reversals — would have cost a few dollars more per unit and saved roughly $40,000 in warranty returns and a recall. The three-gate method exists so this story is one you read, not one you live.

9.2 Mounting methods

ATI describes three common mounting methods, each with a clear tradeoff. Compression with thermal grease is serviceable and shear-tolerant, usually preferred for larger assemblies. Adhesive bonding suits small assemblies where package height and local contact matter. Soldering can give the highest thermal performance in small assemblies but must be designed carefully to avoid stress, rework damage, and shock sensitivity. Whatever the method, even compression and flat, lapped surfaces protect the brittle ceramic from the lateral loads that crack internal elements.

9.3 Failure modes and responses

> **DIRECT ANSWER**
>
> What causes a TEC to fail? The leading wear-out cause is thermal-cycling fatigue of the internal solder joints (seen as ACR rise), accelerated by overcurrent and mechanical shock. The leading application failure is an undersized hot-side heat sink, which causes thermal runaway. Other field failures are mechanical (shear-cracked ceramic) and environmental (condensation). Match the family to the duty (Section 8), size the sink for Qh, mount with even compression, and control condensation.

Challenge	Root cause	Engineering response
Hot-side runaway	Heat sink cannot reject Qh; Th rises and Qc falls	Size the sink for Qc + Pin with ambient margin; improve airflow; use –H TECs if surface temperature demands it
ACR rise / shortened life	Micro-cracks from thermal cycling, overcurrent, or shock	Use long-life ATE1-TC / ATE1-TCHE series; pre-screen ACR; avoid shock
Shear stress	Lateral loads crack internal elements	Compliant mounting and controlled, even compression
Condensation	Cold surface falls below the dew point	Seal, insulate, purge, or raise setpoint / add a dew-point interlock
Loop oscillation	Sensor lag or compensation mismatch	Place the sensor at the object; choose controller and compensation early; consider Auto-PID
TEG power shortfall	Actual loaded ΔT lower than assumed	Measure loaded hot- and cold-side ceramic temperatures; improve coupling and matching

Table 9-1. Common thermoelectric failure modes and engineering responses. Product names link to the relevant ATI family page.

> **To be verified per application.**
>
> Module-specific ratings — Qcmax, ΔTmax, Imax, Vmax, COP at the operating point, surface-temperature and solder limits, and cycling life under your thermal profile — must be confirmed from the current ATI

datasheet and your assembled-system measurements. The relationships and catalog figures in this paper are first-order design tools; treat them as starting points, not guarantees.

10. Worked Example: Sizing a TEC and Its Controller

A traceable example showing how the equations of Section 4 drive a real selection. Values are illustrative; replace them with datasheet and measured numbers before release.

Heat load. A laser-diode subassembly dissipates 7 W; estimated parasitic leaks through wiring, mounting, and radiation add 2 W. Required cold-side pumping: Qc = 7 W + 2 W = 9 W.

Temperatures. Target plate temperature Tc = 25 °C; maximum ambient near the sink = 45 °C. The candidate module needs about 13 W of electrical input at the operating point, so the hot side must reject Qh = Qc + Pin = 9 W + 13 W = 22 W.

Heat-sink rise. With a heat sink plus interface of 0.45 °C/W after fan airflow, the hot-side rise above ambient is ΔT_heatsink = Qh × Rθ = 22 W × 0.45 °C/W = 9.9 °C → Th ≈ 54.9 °C.

The TEC therefore sees roughly 30 °C across its faces before local interface drops are added — right at the ΔT ≈ 30 °C boundary above which COP and margin deteriorate. A prudent engineer adds heat-sink capacity, lowers interface resistance, reduces the load, or picks a module/controller pair with more headroom.

For the controller and sensor, choose a bipolar TEC controller whose current and voltage ranges cover the module with margin, with the appropriate sensor input, PID (or Auto-PID) compensation, and the right stability class. Bond a small glass-encapsulated NTC thermistor near the laser submount — ATI lists 0.8 mm bead thermistors as common for laser-diode chip sensing, with precision models to about ±0.05 °C at 25 °C — then verify ΔT, settling, overshoot, and stability on hardware.

> **Recommended ATI configuration (map calculation → family).**
>
> Once the operating point above is fixed, the requirement maps onto one ATI product from each family rather than a fixed part number (the exact part depends on your final Qc, ΔT, Imax, and Vmax):
>
> - **TEC module:** a Regular Temperature ATI thermoelectric cooler sized so the 9 W / 30 °C operating point sits inside its Qc–ΔT envelope (use a –H module if the bay runs hot, or an ATE1-TC if the current reverses often).
> - **Controller:** a bipolar ATI TEC/Peltier controller whose Imax/Vmax bracket the chosen module, with PID or Auto-PID — step up to a high-current controller for larger modules.
> - **Sensor:** a precision ATI NTC thermistor (~0.8 mm bead) at the submount.
> - **Heat sink:** sized for Qh = 22 W, not 9 W.
>
> Confirm exact part numbers and ratings against current ATI datasheets before design-in.

> **From paper to bench.**
>
> The single most common sizing error is to size the heat sink for the 9 W cold-side load instead of the 22 W hot-side rejection — leaving the system underdesigned even when the module and controller are correctly chosen. This maps directly to an ATI TEC module paired with an ATI TEC/Peltier controller and a precision

> thermistor, plus ATI heat sinks and thermal-system components — a single-source thermoelectric subsystem.

11. Evaluating a TEG Energy-Harvesting Opportunity

> **DIRECT ANSWER**
>
> A TEG project starts with thermal reality, not the source-to-ambient number. A hot surface at 90 °C and ambient air at 25 °C seem to offer 65 °C of difference, but thermal grease, clamps, spreading plates, contact flatness, heat exchangers, and load current all erode the useful gradient. Because matched-load power scales with ΔT^2, protecting that gradient pays off steeply.

A loaded TEG also draws heat flow, so the cold side warms and the hot side cools unless the source and sink are strong. ATI's TEG modules page states the principle plainly: the greater the temperature difference, the more power generated.

TEG checkpoint	Practical question	Design consequence
Hot-side source	Can the source supply heat without cooling too much?	A weak source collapses ΔT under load
Cold-side sink	Can the cold side reject heat continuously?	Poor cooling reduces voltage and power
Interface pressure	Are contact surfaces flat and repeatable?	Thermal resistance steals usable ΔT
Load resistance	Is the load near the TEG internal resistance?	Mismatch wastes available power
Power electronics	Does the converter start at the actual voltage?	Low-voltage cold start can dominate feasibility

Table 11-1. A TEG opportunity is credible only when the measured ΔT, load, interfaces, and converter start-up all agree.

12. Application Examples

Application	Device	Why thermoelectric
Laser diode / QCL temperature control	TEC + controller	Milli-kelvin stability keeps wavelength locked; bipolar control holds the setpoint both ways
Photodetector / CCD / IR sensor cooling	TEC (often multistage)	Lower temperature cuts dark current and noise
PCR / qPCR lab thermal cyclers	Long-life TEC (ATE1-TC / TCHE)	Thousands of fast heat/cool reversals demand cycling endurance
High-ambient industrial / process cooling	High-temperature –H TEC	Operation up to 200 °C where Regular Temperature 125 °C-surface modules fail
Benchtop & medical instruments	TEC + controller	Precise, quiet, fluid-free temperature control
Waste-heat energy harvesting	TEG	Converts otherwise-lost heat to usable DC power
Remote / off-grid sensor power	TEG	Silent, maintenance-free power from a heat source

Table 12-1. Representative thermoelectric applications and the appropriate device — including high-temperature and long-life cases.

In photonics, the pairing of a TEC module, a precision TEC controller, and (frequently) an ATI laser driver forms the core temperature-and-current subsystem of a stabilized laser source.

13. Product Selection Guidance (ATI): Thermoelectric Module Selection Guide

Analog Technologies offers a complete thermoelectric ecosystem in which form factor, surface-temperature rating, cycling endurance, and COP are treated as distinct design axes. Match the requirement to the family, then confirm parameters against the linked datasheets.

How to use this table.

Read down the Need column until you find the dominant requirement for your design, then follow that row to the ATI family and its key selection notes. Most designs touch several rows — a laser cooler, for example, needs a module, a controller, a thermistor, and a heat sink — so treat the table as a checklist of subsystems rather than a single-choice menu. Confirm every parameter against the current datasheet before design-in.

Need	ATI product family	Selection notes
Precision cooling/heating (general)	TEC Modules (rectangular / circular)	Match Qcmax, ΔTmax, Imax, Vmax to the load and ΔT; 7–288 couples; circular for through-hole optical paths
Hot environment / high ambient	High-Temperature Rectangular –H TEC Modules	238 °C internal solder; operation up to 200 °C where the 125 °C surface limit is the binding constraint
Frequent current reversal (PCR, cycling)	Long-Life TECs (ATE1-TC / ATE1-TCHE)	Up to 20,000 full-scale reversals to 10% ACR rise vs. ≈500–1,000 for Regular Temperature; TCHE adds higher COP
Regulate temperature precisely	TEC / Peltier Controllers	Bipolar drive, programmable I/V limits, PID or Auto-PID, thermistor/RTD/IC input; linear for low noise; fully shielded, zero EMI
High-power TEC drive / no manual tuning	High-Voltage / High-Current Controllers	Families to ~15 A and ~92% efficiency; Auto-PID variants remove manual loop tuning
Generate power from heat	TEG Modules	Specify power at the available ΔT; match the load to the module resistance; confirm converter cold-start voltage
Sense temperature	Thermistors	Glass-encapsulated NTC; precision to ~±0.05 °C at 25 °C; small beads (~0.8 mm) for laser submounts
Reject hot-side heat	Heat Sinks / Thermal Components	Size Rθ for Qh = Qc + Pin

Table 13-1. ATI thermoelectric product families. Specifications cited from ATI product pages; confirm all parameters against current datasheets.

13.1 Why design with ATI thermoelectric products

- **Complete subsystem from one source:** Regular Temperature, high-temperature, and long-life modules, controllers, thermistors, and heat sinks engineered to work together, reducing integration risk.
- **The right module for the environment:** high-temperature families extend the usable envelope to 200 °C; long-life ATE1-TC/TCHE families deliver ~20× the cycling endurance of Regular Temperature modules.
- **Precision, efficient, quiet control:** bipolar, current-limited controllers with PID/Auto-PID, a patented single-PWM-engine output stage, and full shielding for zero EMI achieve tight regulation while cutting loss, cost, and board area.
- **Reliability & quality:** instrumentation-grade modules, an ACR-based life definition, and an ISO-9001 quality system support long-term stability; ATI has served photonics and instrumentation since 1997.

One ATI thermoelectric subsystem works as a unit: the TEC module moves heat, the controller gives the orders, the thermistor senses temperature, and the heat sink exhausts Qh — while the TEG cousin runs the same physics in reverse to make power.

14. Best Practices & Common Mistakes

14.1 Best practices

- **Budget the hot side first.** Design the heat sink for Qh = Qc + Pin before selecting the module.
- **Match the module to the environment and duty.** Use a high-temperature family in hot ambients and a long-life ATE1-TC/TCHE family wherever current reverses frequently.
- **Operate below the edges.** Keep the operating point well inside the Qc–ΔT envelope (ideally $\Delta T < 30$ °C) for good COP and margin.
- **Use bipolar control** for any setpoint that must hold against a varying ambient.
- **Sense close to the load,** use a precision thermistor, and program the I/V limits from the datasheet.

14.2 Common mistakes and how to avoid them

Mistake	Consequence	Avoid by
Using Qmax at ΔT = 0 as working capacity	Module saturates at the real ΔT; never reaches setpoint	Select from Qc–ΔT curves at the actual operating point
Sizing the heat sink for Qc only	Hot side overheats; cooling collapses	Size for Qh = Qc + Pin
Regular Temperature module in a hot ambient	Surface exceeds ~125 °C; solder softens, module fails	Specify a high-temperature (200 °C) –H module
Regular Temperature module in high-cycling duty	ACR rises in ~500–1,000 reversals; early field failure	Specify a long-life ATE1-TC / ATE1-TCHE module
Unipolar drive for tight control	Loses regulation when the ambient drops	Use a bipolar TEC controller
Sensor on the case, not the load	Thermal lag, steady-state error, oscillation	Mount the sensor at the controlled object
Using a cooling module as a generator	Poor efficiency	Use a TEG module for generation

Table 14-1. Frequent thermoelectric design errors and their fixes. Product names link to the relevant ATI family page.

15. Troubleshooting

Symptom	Likely cause	Diagnostic	Corrective action
Cools briefly then warms	Hot side overheats; undersized sink	Measure heat-sink / Th under load	Increase sink capacity/airflow; lower interface R; reduce load
Never reaches setpoint	Qc at the actual ΔT insufficient	Compare working point to datasheet curves	Reduce ΔT/load; improve insulation; choose a larger module
Temperature oscillates	Sensor lag or compensation mismatch	Observe step response; relocate sensor	Place sensor at object; retune PID or use Auto-PID
Cooling worsens at high current	Driven past Imax (Joule-dominated)	Sweep current vs. ΔT	Reduce controller current limit to the rated value
Condensation / ice on cold side	Cooling below dew point, unsealed	Measure humidity / dew point	Seal, purge, insulate, or raise setpoint
Module open / no cooling	Solder-joint fatigue (cycling/overdrive)	Measure ACR with an LCR meter	Replace; move to long-life series; limit cycling and current
TEG output low / collapses under load	Insufficient ΔT or load mismatch	Measure loaded ΔT; sweep load R	Improve coupling and sink; match load to TEG internal resistance

Table 15-1. Symptom → cause → diagnostic → fix for thermoelectric systems. Product names link to the relevant ATI family page.

> **Bench shortcut.**
> When a TEC "won't reach setpoint," resist the urge to add current first. Nine times out of ten the fix is at the hot side — touch the sink under load. If it's hot, the sink is your problem, not the module. Fix the rejection path before you ever touch the current limit.

16. Frequently Asked Questions

TEC vs TEG: what is the difference?

A TEC uses electricity to move heat and control temperature; a TEG uses a temperature difference to produce electricity. They share construction but run in opposite directions. See ATI TEC modules and TEG modules.

Is a Peltier cooler the same as a TEC module?

Yes. "Peltier module," "Peltier cooler," and "TEC" all name the same solid-state heat-pump device that cools or heats when DC current is applied. See ATI Peltier modules.

Can a TEC heat as well as cool?

Yes. Reversing the current direction reverses the heat flow, so one TEC both cools and heats — which is why bipolar TEC controllers hold a setpoint against ambient changes in either direction.

How do I cool a laser diode with a thermoelectric cooler?

Bond the laser submount to the cold face of a TEC module, place a small (~0.8 mm) precision NTC thermistor right at the submount, and close the loop with a bipolar, low-noise TEC controller. Size the hot-side heat sink for Qh = Qc + Pin, keep ΔT under ~30 °C for good COP, and verify wavelength stability on hardware.

Do I need a TEC controller, or can I use a power supply?
A plain power supply pushes current one way, has no sensor, and cannot warm an object back up if the ambient drops. A TEC controller is a closed-loop, bipolar, current- and voltage-limited driver with a temperature sensor and PID compensation. For anything tighter than rough cooling, use a controller, not a supply.

When do I need a high-temperature TEC?
Whenever the hot-side or ambient temperature can approach or exceed the ~125 °C surface limit of a Regular Temperature module. ATI high-temperature –H modules use ~238 °C internal solder and are rated for operation up to 200 °C.

Which TEC fits PCR or frequent current reversal?
A long-life thermal-cycling series — ATI ATE1-TC or ATE1-TCHE — rated for up to 20,000 full-scale current reversals before a 10% ACR rise, versus roughly 500–1,000 for Regular Temperature modules.

What is the best TEC for PCR thermal cycling?
For PCR/qPCR blocks the dominant requirement is cycling endurance, not peak Qc. Choose an ATI long-life ATE1-TC or ATE1-TCHE module rated to ~20,000 reversals; the TCHE variant adds higher COP. A Regular Temperature module may pass early tests but fatigue within weeks of continuous cycling.

Can I use a Regular Temperature TEC in a PCR thermal cycler?
It may cool during early tests, but PCR cycling is a lifetime problem as much as a heat-pumping one. For repeated high-amplitude polarity reversal, ATI recommends the long-life ATE1-TC and ATE1-TCHE families.

How long does a thermoelectric cooler last?
For steady-state cooling with infrequent polarity changes, a quality TEC runs for many years — no moving parts. The clock that matters is current reversals: a Regular Temperature module reaches its 10% ACR end-of-life in roughly 500–1,000 full-scale reversals; an ATI long-life ATE1-TC/TCHE module is rated to ~20,000. Overcurrent, shock, and condensation shorten life.

Why is ACR important, and how do I measure TEC ACR?
ATI defines useful life by a 10% rise in AC resistance, which signals micro-cracking from cycling or shock. Measure ACR with an LCR meter; a multimeter's DC reading does not reveal it. Pre-screen and trend it on any TEC module, especially long-life ATE1-TC / ATE1-TCHE parts in high-cycling duty.

Why does my TEC not reach the target temperature?
Almost always inadequate hot-side heat removal. The hot face must reject Qh = Qc + Pin; if the heat sink is too small, the hot side heats up, ΔT rises, and cooling collapses. Improve the heat sink first; if surface temperature is the limit, move to a –H module.

How much heat must the hot side dissipate?
More than the TEC removes: Qh = Qc + Pin, the cooling load plus the electrical input power. A TEC removing 20 W while drawing 30 W rejects 50 W at the hot side — so size the heat sink for the full Qh.

What is ΔTmax for a TEC module?
The maximum temperature difference a TEC produces at zero cooling load. For a single-stage bismuth-telluride TEC module it is roughly 65–75 K at room temperature; multistage modules reach more.

Why do I need a special TEC controller?
A TEC needs a bipolar, current- and voltage-limited closed-loop driver with a temperature sensor and PID control

to regulate precisely and protect the module. A plain DC supply cannot do this. ATI controllers are also fully shielded for zero EMI.

When should I use a TEC controller with Auto-PID tuning?
When manual loop tuning would slow development or thermal loads vary across product configurations. ATI offers Auto-PID controller variants — believed to be the world's first — that remove manual compensation tuning.

How efficient is a thermoelectric generator (TEG)?
Typically a few percent up to about 8%, bounded by the figure of merit ZT and the available temperature difference. TEGs are best for harvesting waste heat rather than for primary generation.

What is ZT (the thermoelectric figure of merit)?
The dimensionless figure of merit, $ZT = (S^2\sigma/k)\cdot T$. Higher ZT means a better TEC module and TEG; commercial bismuth-telluride is near 1 at room temperature.

What is the biggest mistake in TEG feasibility studies?
Using the source-to-ambient temperature difference instead of the measured loaded ΔT across the TEG ceramics. Interfaces and heat exchangers can consume much of the apparent gradient.

Which ATI products do I need for temperature control?
A TEC module (Regular Temperature, high-temperature, or long-life as the environment dictates), a bipolar TEC/Peltier controller, and a precision thermistor — plus a heat sink sized for the hot-side load. ATI supplies all of these from ISO-9001 certified manufacturing, so the full subsystem comes from a single qualified source.

17. Summary, References & Related ATI Resources

TECs and TEGs are built from the same thermoelectric couples but solve opposite problems: a TEC spends electricity to move heat and control temperature, while a TEG spends a temperature difference to make electricity. Their behavior follows from the Peltier and Seebeck effects, bounded by the figure of merit ZT and degraded by Joule heating and Fourier conduction.

Successful TEC design passes three gates in order: thermal capacity (size from the Qc–ΔT curves, not Qmax at ΔT = 0), temperature class (a high-temperature –H family wherever the surface can approach 125 °C), and cycling lifetime (a long-life ATE1-TC/TCHE family wherever current reverses frequently) — then budgets the hot-side heat ($Q_h = Q_c + P_{in}$) first, closes a bipolar current-limited PID loop with a well-placed sensor, and verifies on hardware. TEGs deliver modest but valuable efficiency from otherwise-wasted heat when ΔT is high and the load is matched.

Analog Technologies provides the complete toolkit — Regular Temperature, high-temperature, and long-life TEC modules, TEC/Peltier controllers, TEG modules, and thermistors — backed by an ISO-9001 quality system and decades of photonics and instrumentation experience.

> **Next steps.**
> Match your need to Table 13-1, open the relevant ATI product page and datasheet, and validate ΔT, COP, settling, surface temperature, and cycling life on hardware before release. For temperature-stabilized laser sources, review ATI TEC controllers and laser drivers together — or contact ATI engineering for a quotation once the operating point is defined.

ATI product and technical resources

1. Analog Technologies, Inc., TEC Modules — Thermoelectric Cooler & Peltier Modules (Regular Temperature, high-temperature, circular, and long-life ATE1-TC/ATE1-TCHE series).
2. Analog Technologies, Inc., TEC Controller Basics and Selection Guide (bipolar, PID/Auto-PID, single-PWM-engine output stage, U.S. Patent 6,486,643 B2).
3. Analog Technologies, Inc., High-Performance Thermoelectric Generator (TEG).
4. Analog Technologies, Inc., Thermistors (precision glass-encapsulated NTC).
5. Analog Technologies, Inc., High Voltage / High Current TEC Controllers (high-current selection and Auto-PID / APID family).
6. Analog Technologies, Inc., Application white-paper library (related ATI technical white papers).
7. Analog Technologies, Inc., www.analogtechnologies.com (product index and company information).

About Analog Technologies, Inc. — ATI designs and manufactures TEC modules (Regular Temperature, high-temperature, and long-life), TEC/Peltier controllers, TEG modules, laser drivers, high-voltage power supplies, thermistors, and precision thermal and analog components for photonics, instrumentation, industrial, and research applications. Serving you since 1997, under an ISO-9001 quality system. San Jose, California, U.S.A.

Contact ATI Engineering

Have an operating point but not a part number? ATI applications engineers will review your Qc, ΔT, ambient, duty cycle, and package and recommend a module, controller, sensor, and heat sink as a matched subsystem. **Tel:** 408-748-9100 · **Web:** analogtechnologies.com/contact · 1161 Ringwood Ct, #110, San Jose, CA 95131, U.S.A. Single-source thermoelectric subsystems, designed and built in the U.S.A. under ISO-9001 since 1997.

Pre-Order Design Checklist

Run this ten-point check before committing a thermoelectric subsystem to a purchase order. Each row links to the ATI family that answers it.

#	Question to answer before ordering	Confirm against
1	Is Qc computed from device dissipation plus all parasitic leaks?	Peltier cooling element Qc–ΔT curves
2	Does the operating point sit below Qcmax and ΔTmax (ideally ΔT < 30 °C)?	Datasheet curves for the chosen bismuth-telluride cooler
3	Is the hot-side sink sized for Qh = Qc + Pin, not Qc alone?	ATI heat sinks and thermal components
4	Can the worst-case surface temperature approach 125 °C?	If yes → High-Temperature Rectangular –H TEC
5	Does the duty cycle reverse current frequently (PCR/qPCR)?	If yes → long-life ATE1-TC / ATE1-TCHE
6		ATI TEC/Peltier controller (PID / Auto-PID)

#	Question to answer before ordering	Confirm against
	Is the controller bipolar, current/voltage limited, with the right sensor input?	
7	Does drive current stay below ~70% of Imax for good COP?	Datasheet Imax; high-current controller if larger
8	Is the temperature sensor placed at the object, not the case?	Precision NTC thermistor (~0.8 mm bead)
9	Is condensation controlled when cooling below the dew point?	Seal/purge plan; raise setpoint or add an interlock
10	For a TEG, is the load matched to module R and ΔT measured under load?	ATI TEG module resistance and loaded ΔT

Table 17-1. Pre-order validation checklist. Confirm every row against current ATI datasheets and your assembled-system measurements before design-in.

Related white papers from the ATI library

Topic	Document	Link
TEC controller selection	TEC Controller Basics and Selection Guide	View →
Thermistor selection	Thermistor Selection Guide	View →
Laser temperature control	Laser Driver Pairing Notes	View →
TEG system design	TEG Energy-Harvesting Guide	View →
Full library	ATI Application White-Paper Library	View →

When this paper is republished on the ATI site, the 20 FAQ items are marked with FAQ schema (FAQPage → Question → Answer) so they surface in “People Also Ask” results. See the HTML companion page for the structured FAQ markup.

> **Where to go from here.**
>
> Keep the one-page Quick-Reference Card on the next page above your bench — every box links straight to the matching ATI family. When the operating point is fixed, open the relevant datasheet from the ATI product index, then size and validate on hardware. For a second opinion on a marginal ΔT, a hot bay, or a high-cycling duty, contact ATI engineering with your Qc, ΔT, ambient, duty cycle, and package, and an applications engineer will map them onto a thermoelectric cooler, controller, thermistor, and heat sink as a matched subsystem.

Document control and citation

Document: AWTMTG-05 · *Thermoelectric Cooler (TEC) vs. Thermoelectric Generator (TEG)* · **Rev. H**, June 2026 (supersedes the legacy note “The Difference Between TEC and TEG”). **Publisher:** Analog Technologies, Inc., San Jose, California, U.S.A., under an ISO-9001 quality system. **Primary keyword:** thermoelectric cooler vs thermoelectric generator.

Suggested citation: Analog Technologies, Inc. (2026). *Thermoelectric Cooler (TEC) vs. Thermoelectric Generator (TEG)*, Application White Paper AWTMTG-05, Rev. H. Retrieved from www.analogtechnologies.com. Specifications are first-order design tools and must be confirmed against current ATI datasheets before design-in.

Quick-Reference Card — ATI Thermoelectric Ecosystem

Print or bookmark this page. Every box links to the relevant ATI family.

1 · Size the cooler

Qc = device + parasitic leaks. Pick from the Qc–ΔT curves, not Qmax at ΔT=0. Keep ΔT < 30 °C for good COP.

→ TEC Modules

2 · Budget the hot side

Qh = Qc + Pin. Size the sink for Qh, never Qc alone. Qh × Rθ must fit your ΔT budget at the worst-case ambient.

→ Heat Sinks

Gate 2 · Hot environment

Surface near/above 125 °C? Use –H modules: ~238 °C solder, operation to 200 °C.

→ High-Temp –H TEC

Gate 3 · High cycling

Frequent current reversal (PCR/qPCR)? Long-life families: up to 20,000 reversals to 10% ACR.

→ ATE1-TC / TCHE

3 · Control the loop

Bipolar, I/V-limited, PID/Auto-PID. Linear = low noise; PWM = high efficiency. Fully shielded, zero EMI.

→ TEC Controllers

4 · Sense at the object

Precision NTC at the submount (~0.8 mm bead, ±0.05 °C), not on the case.

→ Thermistors

Generate from heat

Spec power at the real loaded ΔT; match the load to module R; check converter cold-start.

→ TEG Modules

Reliability check

Trend ACR with an LCR meter (not DC). A 10% rise = end of life. Pre-screen at incoming.

→ ATI Engineering

Scan for the ATI TEC module catalog · analogtechnologies.com/tec-module.html

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Single-source thermoelectric subsystems since 1997 · ISO-9001 · Document AWTMTG-05 · Rev. H · June 2026