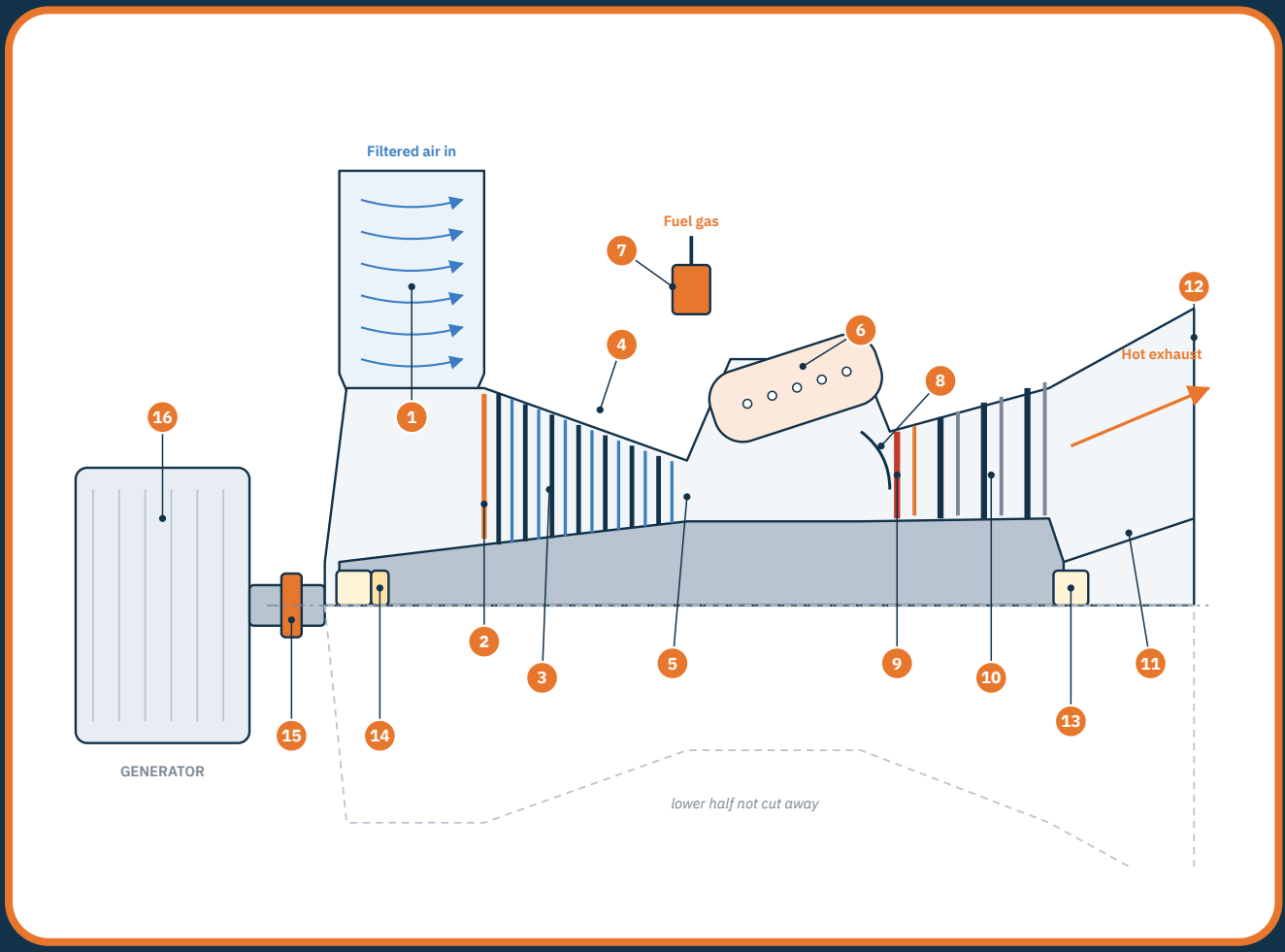
PlantCalcKit

Gas Turbines, HRSG and Compressors Made Simple

A field guide to gas turbines, heat recovery and compressors

The gas turbine cycle · output and heat rate · ISO corrections · degradation and washing · exhaust energy · HRSG pinch and approach · combined cycle · compressor curves · polytropic head · surge and anti-surge · reciprocating compressors · troubleshooting · economics



FREE SAMPLER — Chapters 1 to 3

Edition 1.0 · November 2026

PlantCalcKit

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Written in our own words from published engineering sources, listed in Appendix G. All diagrams, picture pages and charts are original PlantCalcKit artwork; every number in the worked examples was computed with the same methods as the PlantCalcKit Excel toolkits named in each chapter. Equipment tags, readings and prices in the examples are generic and illustrative. Methods taken from published test codes are described as aligned with the publicly documented method; this book is not a copy of any code and does not replace one.

This guide is for training and engineering estimates. It does not replace the equipment maker's instructions, the official test codes, a formal acceptance test run to the published test code, the plant's control and protection settings, or your plant's safety rules and procedures.

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GUIDE

How to use this book

This book explains gas turbines, heat recovery steam generators (HRSGs) and the compressors that move a plant's gas, in plain words. You do not need to be an expert. If you can read a gauge, follow a recipe and use a calculator, you can follow every page.

Who it is for

- **Operators** who start, load, watch and wash these machines every shift.
- **Young engineers** who must check a test, explain a trend or defend a number in a meeting.
- **Senior engineers** who want a quick refresher, a formula sheet and a set of checklists to hand to the team.

How the book is built

The book has five parts. Read them in order, or jump to the part you need today.

Part	What you learn	Chapters
A	How a gas turbine works, what output, heat rate and efficiency mean, and the parts inside	1 to 4
B	Why output changes with the weather, how to correct a test to ISO conditions, how machines wear and how washing helps	5 to 8
C	How much heat leaves in the exhaust, how an HRSG turns it into steam, pinch and approach, stack temperature and combined cycles	9 to 13
D	Compressor types, head and polytropic efficiency, curves and their correction, surge and anti-surge control, reciprocating machines and staging	14 to 18
E	Monitoring, troubleshooting and the money behind every gap	19 and 20

At the back you will find frequently asked questions, a units table, a formula sheet, property tables, printable checklists, a glossary, the answers to every quiz and Try it exercise, and the list of sources.

The boxes you will see

- **Field check** — what to look at on the plant, what it may mean and the first thing to check.
- **Engineer's calculation corner** — a worked example, step by step, with every number shown.
- **Try it** — a short exercise for you. Answers are in Appendix F.
- **Watch out** — a common mistake or a safety point.
- **Try it with PlantCalcKit** — the free calculator or Excel toolkit that does the sum for you, with a QR code.
- **Quick quiz** — five questions at the end of each chapter. Answers are in Appendix F.
- **Picture pages** — a cutaway drawing with numbered parts and a parts table.

Units

SI units come first, with US units in brackets where it helps: 32 °C (90 °F), 100.6 kPa (14.59 psia), 40,000 kW (40 MW). Pressures are absolute (bar a, kPa a) unless the text says gauge (bar g). Heat rate is in kJ/kWh; to get Btu/kWh, multiply by 0.9478. Appendix A has a full conversion table.

Our running examples

The same machines appear all through the book. Each one is the example case of a PlantCalcKit Excel toolkit, so you can open the toolkit and see the same numbers.

Tag	What it is	Main chapters
GT-101	40 MW class single-shaft gas turbine generator, daily log on a 32 °C afternoon	3, 5, 20
GT-102	Twin of GT-101; formal test point and a year of trend points	6, 7, 8
GT-103 + WHB-301	31 MW gas turbine with a single-pressure waste heat boiler making 30 bar g steam	9, 10, 12
H-201	Dual-pressure HRSG (60 bar a and 8 bar a) behind a 100 kg/s exhaust	11, 12
CC-1	Two gas turbines, two HRSGs and one steam turbine (a "2 × 1" combined cycle block)	13
K-101	Centrifugal natural gas compressor, 30 bar a suction, 9,800 rpm	15, 16
K-102	Centrifugal process gas compressor with an anti-surge recycle valve	17
K-201	Two-stage double-acting reciprocating compressor	18
K-301	Multistage compressor with intercoolers, 5 to 60 bar a	18, 20

LIMITS OF THIS BOOK

Read this first. Gas turbines, HRSGs and compressors run hot, fast and at high pressure. Fuel gas leaks, surge, overspeed, hot surfaces, confined spaces and stored energy can kill. This book helps you understand and check performance. It does **not** replace the maker's instructions, the plant's control and trip settings, permits to work, isolation procedures or a formal acceptance test run to the published test code. Never change a protection setting, a surge line, an anti-surge controller or a trip point because of a calculation in this book. Use the numbers here to ask good questions, then follow your plant's approved procedures and involve the people responsible for the equipment.

Free tools

Every chapter ends with a box that names the PlantCalcKit tool that does its calculation. The free online calculators below need no sign-in. Scan a code with your phone camera.


Compressor head and power


Gas density and Z factor


Humid air (psychrometrics)


Steam tables (IAPWS-IF97)


Excess air from fuel gas


Unit converter


Heat exchanger LMTD


Control valve Cv for gas


All free calculators


Excel shop and e-books

The Excel toolkits that match this book (each has the same example case as our running examples):


Gas Turbine Performance


Gas Turbine Performance Correction


Gas Turbine Exhaust Energy Recovery


HRSG Thermal Performance


HRSG Pinch and Approach Analysis


Combined Cycle Plant Performance


Centrifugal Compressor Performance


Compressor Performance Curve Correction


Compressor Anti-Surge Margin Evaluation


Reciprocating Compressor Performance


Compressor Intercooling and Staging


Steam Turbine and Compressor Train Performance

PART A

How a gas turbine works

The cycle, the numbers that describe it, and the parts that make it run.

CHAPTER 1

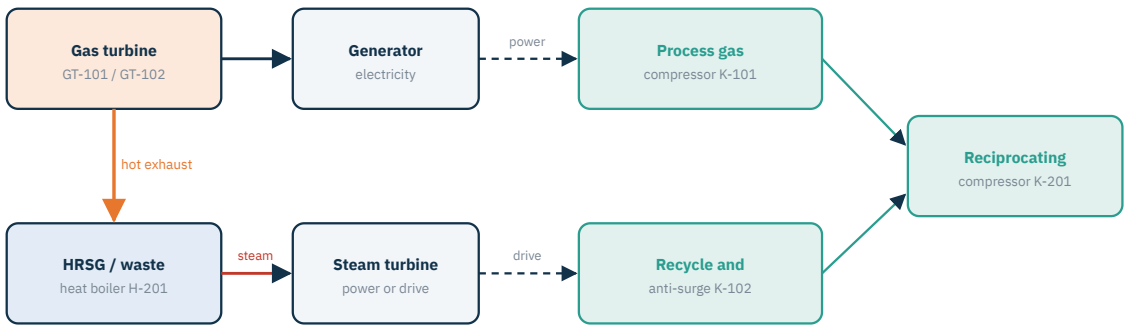
Why plants use gas turbines and compressors

A gas turbine turns fuel into shaft power fast, in a small space, with little water. A compressor uses shaft power to push gas from low to high pressure. Between them they move much of the energy and most of the gas in a modern process plant.

1.1 Three jobs for a gas turbine

Gas turbines do three main jobs in industry:

- **Making electricity.** The turbine drives a generator. A plant may export power to the grid or use it for its own motors. GT-101 and GT-102 in this book are 40 MW class units of this kind.
- **Driving a machine directly.** Pipelines, gas processing plants and offshore platforms use gas turbines to drive large compressors and pumps. This is called **mechanical drive**. The turbine and the compressor often run at variable speed together.
- **Making heat as well as power.** The exhaust of a gas turbine is hot, usually between 450 and 600 °C (840 to 1,110 °F). A heat recovery steam generator (HRSG) behind the turbine turns that heat into steam. When both power and heat are used, we call it **cogeneration** or combined heat and power. When the steam drives a steam turbine to make more electricity, we call it a **combined cycle**.



Fuel in, power and steam out; compressors move the plant's gas. Tags are the running examples of this book.

Figure 1.1 — Where the machines in this book sit in a plant. Fuel goes in; electricity, shaft power and steam come out; compressors move the plant's gas. The tags are the running examples used in every chapter.

1.2 Why a gas turbine and not something else?

A gas turbine has some strong points:

Good points	Weak points
High power from a small, light machine	Output falls on hot days and at high sites
Starts and loads in minutes	Efficiency on its own is modest: about 30 to 40 %
Needs little cooling water	Needs very clean air and clean fuel
Hot exhaust is easy to use for steam	Wear and fouling slowly cut output; needs washing
Low emissions with natural gas	Expensive hot-section parts and inspections

The main weak point is efficiency. A simple-cycle gas turbine throws away about two thirds of its fuel heat in the exhaust. That is why so many plants add an HRSG. With heat recovery, the useful share of the fuel can rise to 70 or 80 %.

1.3 Why compressors matter just as much

A compressor raises the pressure of a gas. Plants need compressors to:

- move natural gas through pipelines and into the plant;
- feed reactors that work at high pressure, such as ammonia, methanol and hydrogen units;
- recycle unreacted gas back to the reactor;
- run refrigeration cycles;
- supply instrument and plant air.

A large compressor can use 5 to 30 MW. It is often the biggest single energy user in the plant. Small gains in its efficiency are worth a lot of money (Chapter 20).

There is also a compressor **inside** every gas turbine. It takes in air and raises its pressure 10 to 30 times before the fuel is burned. That compressor uses about half of the power the turbine makes. So everything you learn about compressors in Part D also helps you understand gas turbines, and the other way round.

1.4 Two ideas that run through the book

Idea 1 — Compare with the right "expected" value. A gas turbine on a 35 °C afternoon gives less power than on a 10 °C morning. A compressor at lower speed gives less head. That is not a fault. Before you say a machine is bad, you must correct the reading to the same reference conditions, or work out what the machine **should** give today. Chapters 5 to 8 and 16 show how.

Idea 2 — Follow the energy. Fuel heat goes somewhere: into power, exhaust, cooling oil, casing losses. Gas heat in an HRSG goes into steam or up the stack. Shaft power in a compressor goes into the gas. If you can draw the energy balance, you can find where the losses are, and you can check whether the instruments make sense.

FROM THE PLANT

The "bad turbine" that was a bad thermometer. A plant saw its gas turbine output fall by 4 % in one week and planned a wash. Before the wash, the shift engineer compared two inlet air temperature readings: one sensor in the sun read 6 K higher than the other. Corrected with the right temperature, the machine was where it should be. The wash was moved to the next planned stop. Check the instruments before you blame the machine (Chapter 19).

1.5 Safety around these machines

Gas turbines and compressors are among the most dangerous machines on a plant. Keep these points in mind every day:

- **Fuel gas** can leak into enclosures. Enclosures have gas detectors, ventilation fans and fire protection for a reason. Never defeat them.
- **Hot surfaces** above 400 °C are normal. Insulation and guards protect you.
- **Rotating parts** can turn on their own when gas flows through a stopped machine. Use the plant's isolation and lock-out procedures.
- **Surge** in a compressor can reverse the flow in a fraction of a second and damage seals, bearings and impellers (Chapter 17).
- **High pressure** gas stores a lot of energy. Depressurise and purge before opening.
- **Noise** levels near a running gas turbine are high. Wear hearing protection.

✓ FIELD CHECK

parts of the plant you can check from the walkway

What you see	What it may mean	First thing to check
Inlet filter differential pressure rising fast	Dust storm, fog, blocked or wet filters	Filter house, drains, weather; Chapter 6
Exhaust temperature spread wider than normal	Combustion problem in one can or burner	Thermocouple health, then combustion tuning
Steam drum level swinging	Load change, feedwater control, foaming	Level transmitters, feedwater valve, water chemistry
Compressor recycle valve opening by itself	Low flow, approach to surge	Process flow, suction pressure; Chapter 17
New noise or vibration	Bearing, coupling, rubbing or surge	Vibration trend; tell the machine engineer

⚙ ENGINEER'S CALCULATION CORNER

How big is the energy flow?

GT-101 burns 7,900 kg/h of natural gas. The lower heating value (LHV) of the gas is 48,174 kJ/kg (Chapter 3 shows how to get it from the gas analysis).

Step 1 — Fuel heat. 7,900 × 48,174 ÷ 3,600 = **105,714 kW**, or about 105,714 kW (361 million Btu/h).

Step 2 — Output. The generator meter reads **33,000 kW**.

Step 3 — What is left. 105,714 − 33,000 = **72,714 kW** leaves as heat, nearly all of it in the exhaust. That is more than twice the electrical output, and it is the heat an HRSG can turn into steam (Chapters 9 and 10).

✎ TRY IT

A gas turbine makes 25 MW of power from 75 MW of fuel heat (LHV). (a) What is its efficiency? (b) About 1 % of the fuel heat is lost from the casing and lube oil, and the generator is 98.5 % efficient. Roughly how much heat leaves in the exhaust?

▶ TRY IT WITH PLANTCALCKIT

Every chapter of this book matches a PlantCalcKit Excel toolkit. The **Gas Turbine Performance** toolkit turns a log reading (fuel flow, gas analysis, output, ambient conditions) into heat rate, efficiency, exhaust flow and the cost of any gap, with the GT-101 example already filled in. The free **unit converter** handles kW, MW, Btu/h and heat-rate units.

Gas Turbine Performance

Unit converter

? QUICK QUIZ 1

1. Name the three main jobs of a gas turbine in industry.
2. What is the difference between cogeneration and a combined cycle?
3. Roughly what share of its fuel heat does a simple-cycle gas turbine lose in the exhaust?
4. Why does a gas turbine's own compressor matter so much for its output?
5. Before you say a machine has lost performance, what must you do with the reading?

CHAPTER 2

The gas turbine cycle in plain words

Every gas turbine does the same four things: it sucks in air, squeezes it, heats it by burning fuel, and lets the hot gas expand through a turbine. Engineers call this the Brayton cycle. Once you see it, you understand why hot days, dirty compressors and high exhaust temperatures matter.

2.1 The four steps

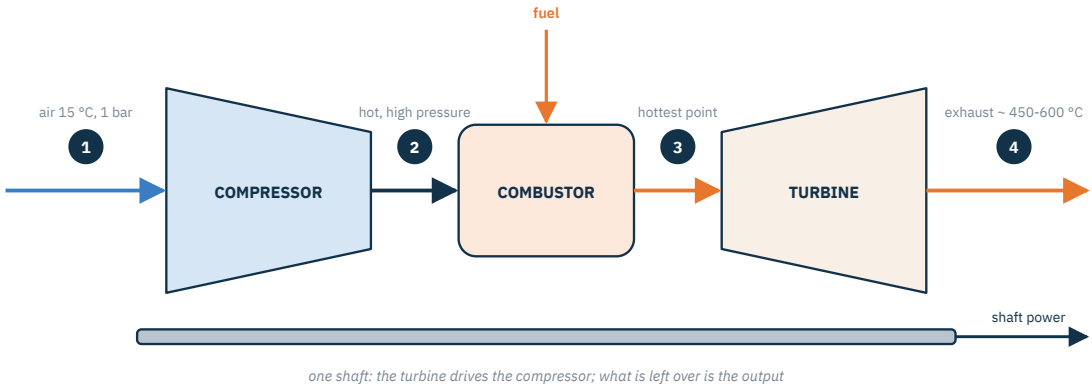


Figure 2.1 — The simple gas turbine. Air (1) is compressed (2), heated by burning fuel (3) and expanded through the turbine to the exhaust (4). The turbine drives the compressor through the shaft; the power left over is the output.

1. **Compression (1 to 2).** The compressor takes air at about 15 °C and 1 bar and raises its pressure 10 to 30 times. Squeezing air makes it hot: at a pressure ratio of 16, a typical compressor delivers air at about 420 °C before any fuel is burned (the worked example below shows the sum).
2. **Combustion (2 to 3).** Fuel burns in the compressed air. The pressure stays about the same, but the temperature jumps to 1,100 to 1,500 °C (2,000 to 2,700 °F) at the turbine inlet. This is the **firing temperature**, the hottest point in the machine.
3. **Expansion (3 to 4).** The hot gas expands through the turbine blades and spins the shaft. Its pressure falls back to almost atmospheric and its temperature falls to about 450 to 600 °C.
4. **Exhaust (4 back to 1).** The gas leaves to the stack or the HRSG. Fresh air enters at the inlet, so the "cycle" is closed by the atmosphere.

2.2 Why the turbine must be bigger than the compressor

Hot gas has more volume than cold air at the same pressure. When it expands through the turbine, it gives out more work than the compressor took to squeeze the cold air. The difference is the **net output**.

In a real machine the compressor uses about half to two thirds of the turbine's work. Engineers call this share the **back-work ratio**. It is large, and it explains a key fact of gas turbine life:

> A small loss in the compressor or the turbine makes a big loss in output.

If the turbine gives 100 units and the compressor takes 60, the output is 40. If fouling makes the compressor take 63 units instead of 60, the output falls to 37: a 5 % compressor loss becomes a 7.5 % output loss.

2.3 What the ideal cycle tells us

Engineering textbooks study an ideal version of the cycle (air only, no friction, constant specific heat). Its efficiency depends only on the pressure ratio *r*:

Ideal efficiency = 1 − 1 / r^((k−1)/k), with k = 1.4 for air

Pressure ratio	4	8	12	16	20	30
Ideal efficiency, %	32.7	44.8	50.8	54.7	57.5	62.2
Air after compression, °C	155	249	313	363	405	488

Two lessons come out of this:

- **Higher pressure ratio, higher efficiency.** That is why modern machines have long compressors with many stages.
- **Higher firing temperature, more work per kilogram of air.** The work curves in Figure 2.2 rises as firing temperature goes up. More work per kilogram means a smaller, cheaper machine for the same power. For each firing temperature there is a pressure ratio that gives the most work; for a firing temperature of 1,127 °C it is about 16.

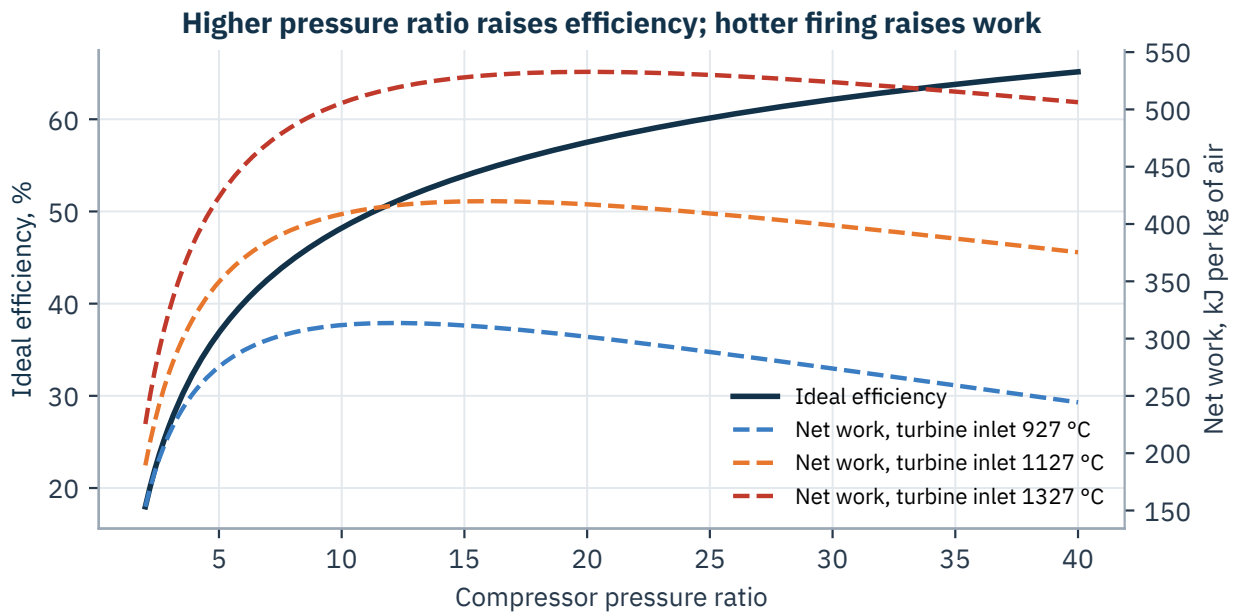


Figure 2.2 — Ideal (cold-air standard) cycle with the inlet at 15 °C. Efficiency rises with pressure ratio. Net work per kilogram of air rises with turbine inlet temperature and has a best pressure ratio for each temperature. Computed for this book from the textbook equations.

2.4 Real machines lose more

Real compressors and turbines are not perfect. Their quality is measured by the **isentropic efficiency**: the ideal work divided by the real work (compressor) or the real work divided by the ideal work (turbine). Good large machines reach 85 to 92 %.

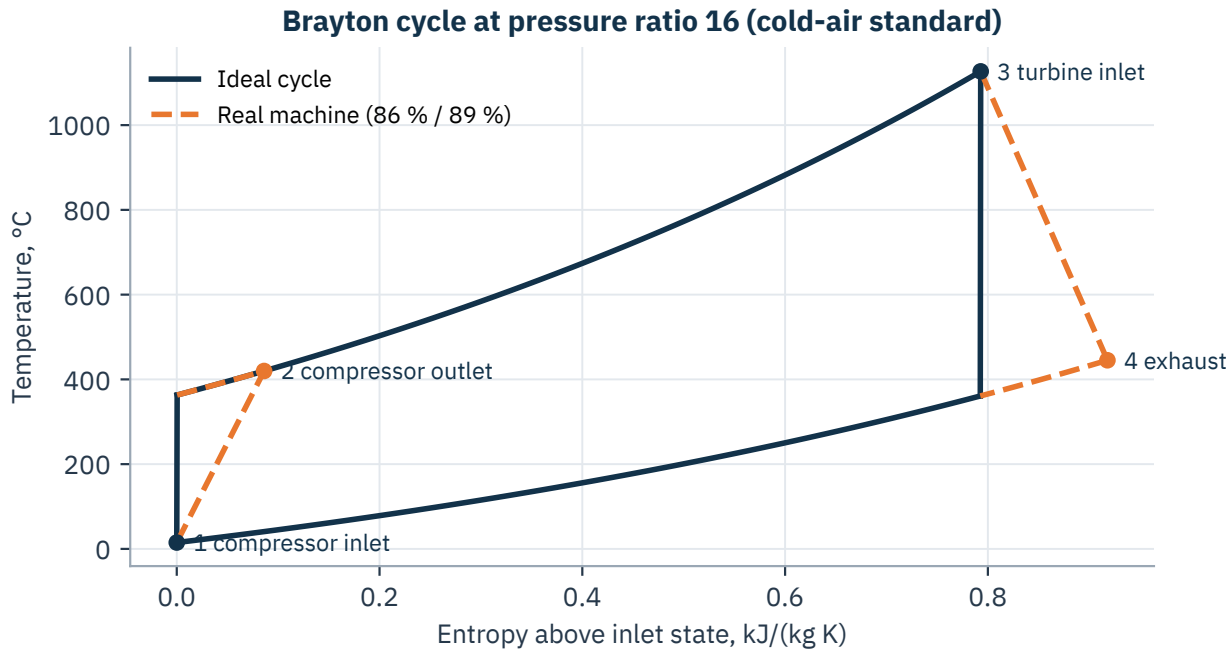


Figure 2.3 — Temperature against entropy for the ideal cycle (solid) and for a real machine with 86 % compressor and 89 % turbine efficiency (dashed). The real compressor delivers hotter air for the same pressure, and the real turbine leaves hotter exhaust.

Real machines also lose some air to cool the hot turbine blades, lose a little pressure in the combustor and inlet ducts, and have specific heats that change with temperature. Makers use detailed models for all this. For understanding and checking, the simple cycle in the box below is enough.

⚙ ENGINEER'S CALCULATION CORNER

A simple cycle at pressure ratio 16

Inlet air 15 °C (288.15 K). Turbine inlet 1,127 °C (1,400 K). Compressor efficiency 86 %, turbine efficiency 89 % (illustrative values). Air: k = 1.4, cp = 1.005 kJ/(kg K) (the textbook cold-air standard).

Step 1 — Ideal compressor outlet. 288.15 × 16^0.2857 = 363 °C.

Step 2 — Real compressor outlet. 15 + (363 − 15) ÷ 0.86 = **420 °C**. Compressor work = 1.005 × (420 − 15) = **407 kJ/kg**.

Step 3 — Turbine. Ideal exhaust = 1,400 ÷ 16^0.2857 = 361 °C. Real exhaust = 1,127 − 0.89 × (1,127 − 361) = **445 °C**. Turbine work = 1.005 × (1,127 − 445) = **685 kJ/kg**.

Step 4 — Net work and efficiency. Net = 685 − 407 = 278 kJ/kg. Heat added = 1.005 × (1,127 − 420) = 711 kJ/kg. Efficiency = 278 ÷ 711 = **39.2 %** (the ideal cycle gives 54.7 %).

Step 5 — What it means. The compressor uses 59 % of the turbine work. To make 40 MW this machine needs about 40,000 ÷ 278 = 144 kg/s of air. The exhaust leaves at 445 °C: hot enough to make good steam.

⚠ WATCH OUT

The firing temperature is set by the control system from the exhaust temperature and the compressor pressure ratio. The machine protects its hot parts by limiting firing temperature. Never ask for "more output" by over-firing. The control limits and the maker's settings come first.

2.5 Single-shaft and two-shaft machines

In a **single-shaft** machine the compressor, turbine and load are on one shaft and turn at one speed. Most heavy-duty generator drives are single-shaft (GT-101 and GT-102). In a **two-shaft** machine, a gas generator (compressor, combustor and high-pressure turbine) makes hot gas, and a separate **power turbine** on its own shaft drives the load. Two-shaft machines suit compressor drives because the load can change speed while the gas generator runs where it is happiest. Chapter 4 shows both.

✎ TRY IT

Use the ideal-cycle formula to find the efficiency of a gas turbine with a pressure ratio of 10 (k = 1.4).

▶ TRY IT WITH PLANTCALCKIT

The **Gas Turbine Performance** toolkit works with the real machine, not the ideal cycle: it builds the heat and mass balance from your readings and shows where the fuel heat goes. For the compressor side of the cycle, the free **compressor head and power** calculator gives the work to compress any gas.

Gas Turbine Performance

Compressor head and power

? QUICK QUIZ 2

1. Name the four steps of the Brayton cycle.
2. Why does a gas turbine's compressor get hot even before any fuel is burned?
3. What is the back-work ratio, and why does it make output sensitive to fouling?
4. What happens to ideal efficiency when the pressure ratio goes up?
5. Why do compressor drives often use two-shaft gas turbines?

CHAPTER 3

Output, heat rate and efficiency

Three numbers describe how well a gas turbine is doing: how much power it makes, how much fuel each kilowatt-hour costs, and what share of the fuel heat becomes power. This chapter shows how to get all three from an ordinary shift log, using GT-101 on a hot afternoon.

3.1 Output

Output is the electrical power at the generator terminals, in kW or MW. Some plants measure **shaft power** at the coupling instead (mechanical drives always do). Generator output = shaft power × generator efficiency. Large generators are about 98 to 99 % efficient; the toolkit default is 98.5 %.

Always note **where** the power is measured, and whether the plant's own auxiliary load (pumps, fans, lube oil, ventilation) has been taken off. "Gross" output is before the auxiliaries; "net" is after.

3.2 Heating value: LHV and HHV

When natural gas burns, its hydrogen forms water. If that water leaves as vapour, as it does in a gas turbine exhaust, its latent heat is not recovered. The **lower heating value (LHV)** leaves the latent heat out. The **higher heating value (HHV)** includes it, as if the water were condensed.

- Gas turbine makers and most of the world quote heat rate and efficiency on the **LHV** basis.
- Gas is often bought and sold on the **HHV** basis.
- For natural gas, HHV is about 1.10 to 1.11 times the LHV.

Always write the basis next to the number. A heat rate of 11,500 kJ/kWh on the LHV basis is the same machine as about 12,700 kJ/kWh on the HHV basis.

The heating value of a gas mixture is the mole-weighted sum of the heating values of its components. The method is aligned with the publicly documented ISO 6976 calculation of calorific values from composition.

Component	Mole % (GT-101 fuel)	LHV, kJ/mol
Methane	94.0	802.6
Ethane	3.2	1,428.6
Propane	0.8	2,043.3
Butanes	0.30	2,648 to 2,657
Pentane and hexane	0.15	3,271 to 3,887
Nitrogen and CO_2	1.55	0

The mixture has a molar mass of 17.22 g/mol, an LHV of **48,174 kJ/kg** and an HHV of 53,365 kJ/kg (ratio 1.108).

3.3 Heat input, heat rate and efficiency

Heat input (kW) = fuel flow (kg/h) × LHV (kJ/kg) ÷ 3,600

Heat rate (kJ/kWh) = heat input (kW) × 3,600 ÷ output (kW)

Efficiency (%) = 3,600 ÷ heat rate × 100

Heat rate is the fuel energy needed to make one kilowatt-hour. **Lower is better.** Efficiency and heat rate say the same thing in two ways: 3,600 kJ is one kilowatt-hour, so an efficiency of 100 % would mean a heat rate of 3,600 kJ/kWh. In US units, multiply kJ/kWh by 0.9478 to get Btu/kWh.

⚙ ENGINEER'S CALCULATION CORNER

GT-101 on a 32 °C afternoon

Shift log: fuel gas 7,900 kg/h (the analysis above), generator output 33,000 kW, ambient 32 °C, 100.6 kPa a, 55 % RH, exhaust 525 °C.

Step 1 — Heat input. 7,900 × 48,174 ÷ 3,600 = **105,714 kW** (LHV).

Step 2 — Heat rate. 105,714 × 3,600 ÷ 33,000 = **11,532 kJ/kWh** LHV (12,775 kJ/kWh on the HHV basis).

Step 3 — Efficiency. 3,600 ÷ 11,532 = **31.2 %** LHV (28.2 % HHV).

Step 4 — Specific fuel consumption. 7,900 ÷ 33,000 = 0.239 kg of gas per kWh.

Step 5 — Is it good? GT-101 is rated 40,000 kW at 10,800 kJ/kWh at ISO conditions (15 °C). Today it gives less power and a higher heat rate, but it is also 17 K hotter than ISO. We cannot judge it yet: Chapter 5 explains the weather effect and Chapter 20 puts a price on the part of the gap that is real.

3.4 Where the fuel heat goes

Every kilowatt of fuel heat ends up somewhere. For GT-101:

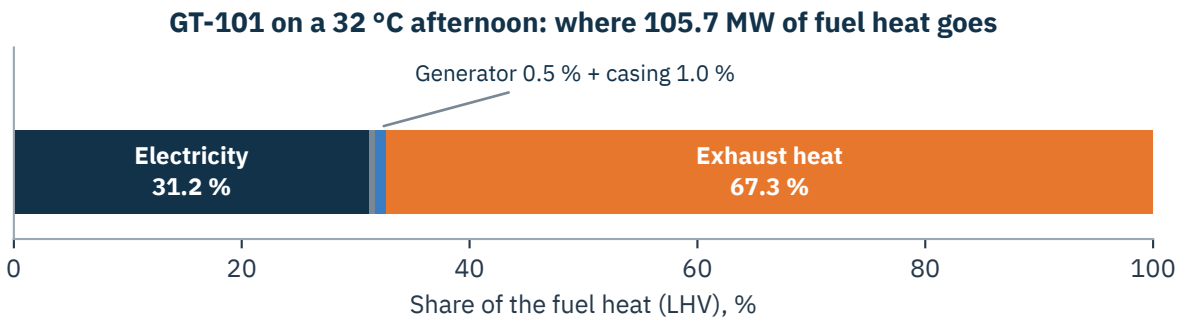


Figure 3.1 — GT-101 energy split, computed from the log above with a generator efficiency of 98.5 % and a casing, lube-oil and other loss of 1 % of the fuel heat (toolkit defaults). About two thirds of the fuel heat leaves as hot exhaust.

The exhaust share is 67.3 %. That is the heat a waste heat boiler or HRSG can use (Part C).

3.5 Exhaust flow from a heat balance

Most gas turbines have no air flow meter. You can estimate air and exhaust flow from an energy balance: fuel heat in = power out + exhaust heat + small losses. The exhaust heat is the exhaust flow × its specific heat × (exhaust temperature − inlet air temperature). For GT-101 the Gas Turbine Performance toolkit finds about **129.3 kg/s** of air, an air-to-fuel ratio of about 59 and an exhaust oxygen content of about 15 % (dry). A 1 % error in fuel flow moves this balance by about 1 % in air flow, so the result is an estimate (the toolkit brief puts it at 3 to 5 % when inputs are good). It is still very useful for HRSG checks.

✓ FIELD CHECK

what to log for a heat-rate check

Reading	Why it matters	Good practice
Fuel flow	Sets the heat input directly	Use the corrected (pressure, temperature, density) flow; check the meter calibration date
Fuel analysis	Sets the heating value	Recent gas chromatograph result, same hour as the test
Generator output	The product	Revenue-grade meter if there is one
Ambient temperature, pressure, humidity	Needed for correction (Chapter 5)	Shaded sensor at the filter inlet
Exhaust temperature	Exhaust heat, firing level	Average of all thermocouples; note the spread
Inlet and exhaust pressure loss	Correction (Chapter 6)	Differential pressure transmitters

⚠ WATCH OUT

Do not mix bases. A heat rate on the HHV basis compared with a guarantee on the LHV basis looks about 10 % worse than it is. Check the basis of the fuel flow (mass or standard volume, and at which standard temperature) for the same reason.

✎ TRY IT

A gas turbine runs at 35 % efficiency (LHV). (a) What is its heat rate? (b) How many kg/h of a gas with LHV 48,000 kJ/kg does it burn to make 30,000 kW?

▶ TRY IT WITH PLANTCALCKIT

The **Gas Turbine Performance** toolkit does every step of this chapter: heating values from a 14-component gas analysis, heat input from mass, volume or energy flow, heat rate and efficiency on both bases, the exhaust balance and the energy split. The free **excess air from fuel gas** calculator checks the air-to-fuel side of the balance.

Gas Turbine Performance

Excess air from fuel gas

? QUICK QUIZ 3

1. What is the difference between gross and net output?
2. Why is the HHV of natural gas larger than its LHV?
3. GT-101 has a heat rate of about 11,500 kJ/kWh. What is its efficiency?
4. Is a lower heat rate better or worse?
5. Why is a calculated exhaust flow only an estimate?

SOURCES

Sources for Chapters 1 to 3

Written in our own words; no text, tables or figures were copied. The full book lists the sources for every chapter in Appendix G.

- **Saravanamuttoo, H.I.H., Rogers, G.F.C., Cohen, H., Straznicky, P.V. and Nix, A.C.**, *Gas Turbine Theory*, 7th edition, Pearson, 2017, chapters 1 and 2 (shaft power cycles, effect of pressure ratio and turbine inlet temperature).
- **Boyce, M.P.**, *Gas Turbine Engineering Handbook*, 2nd edition, Gulf Professional Publishing (Butterworth-Heinemann), 2002, chapter 1 (gas turbine types and applications).
- **Çengel, Y.A. and Boles, M.A.**, *Thermodynamics: An Engineering Approach*, 8th edition, McGraw-Hill, chapter 9 (Brayton cycle, cold-air standard).
- **ISO 6976:2016**, *Natural gas — Calculation of calorific values, density, relative density and Wobbe indices from composition* (heating value from composition; method aligned with the publicly documented calculation).
- **ISO 3977-2:1997** and **ISO 2314:2009** (reference conditions for gas turbine ratings and tests).
- **NIST Special Publication 811**, 2008 edition (unit conversions).
- PlantCalcKit **Gas Turbine Performance** toolkit (example case of GT-101; generic data).

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