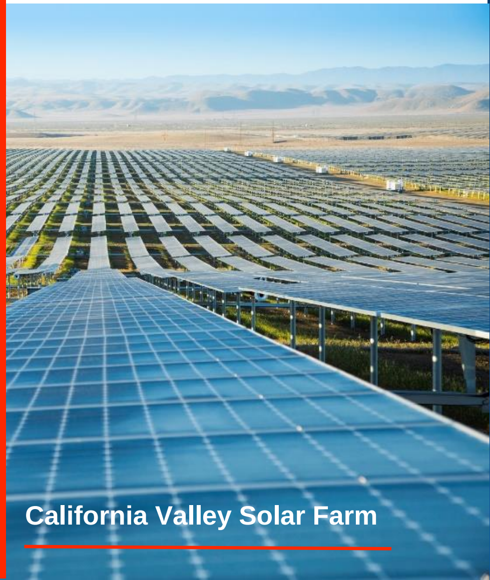
ENERGY

INFRASTRUCTURE

MINING & METALS

NUCLEAR, SECURITY
& ENVIRONMENTAL


California Valley Solar Farm


Temple II, Texas

sCO2 Reality Check

John Gülen, ASME Fellow, Bechtel Fellow

7th International Supercritical CO2 Power Cycles Symposium

February 22, 2022

Engineering the Extraordinary since **1898**

25,000 extraordinary projects in **160** countries on all **7** continents.

12,000+
colleagues worldwide

100+
nationalities

\$17.6
Revenue in billions of U.S. dollars

\$7.1
New work booked in billions of U.S. dollars

Bechtel is a trusted engineering, construction, and project management partner to industry and government. Differentiated by the quality of our people and our relentless drive to deliver the most successful outcomes, we align our capabilities to our customers' objectives to create a lasting positive impact.

Bechtel Corporation

We share best practice, talent, lessons learned, and technology across the whole group.

Bechtel's four global business units are trusted engineering, construction, and project management partners to industry and government. We align our capabilities to our customers' missions with safety, quality, ethics, and integrity.

Infrastructure HQ
London, United Kingdom

Oil, Gas & Chemicals HQ
Texas, United States

Nuclear, Security & Environmental HQ
Virginia, United States

Mining & Metals HQ
Santiago, Chile

Nuclear, Security & Environmental

- 80% of nuclear plants in the U.S., and 150 worldwide designed, serviced, or delivered by Bechtel
- Construction and operation of national security facilities
- Building the world's largest and most complex radioactive waste treatment plant

Vogtle overall site, United States

Energy

- 1/3 of global LNG capacity currently under construction
- 275+ refinery expansions and modernizations
- 50,000 miles (80,500 km) of pipeline systems
- 380+ major chemical and petrochemical projects

Curtis Island LNG, Australia

Mining & Metals

- 200 million metric tons per annum of installed iron ore productions
- 42 major copper projects
- 30 aluminium smelter projects
- 8 alumina refinery projects

Fjardaal Aluminium Smelter, Iceland

Infrastructure

- 300 subway and rail projects
- 17,200+ miles (27,700 km) of highways and roads
- 6,200+ miles (10,000 km) of railroads
- **390 individual power plants**

Reading Station, United Kingdom

Services We Offer

Wind Projects

Onshore and Offshore

- Medium voltage collection system layout
- Wind turbine micro-siting
- Turbine & tower transport logistics
- WTG erection and mechanical completion
- Levelized cost of energy & bankability analysis
- Technology and conceptual design options analysis
- Offshore foundation and structural design
- High voltage AC and DC platform design
- Managing vessels and subcontractors
- Staging port assessment & design
- Crane operation analysis and critical lifting analysis

Solar Projects

PV, CPV, and CSP

- PV system size optimization
- PVSYST® production estimates
- Levelized cost of energy & financeability analysis
- Technology trade-off analysis
- Site work
- Pile capacity testing
- Foundation & structural design
- Receiver/boiler & power block optimization
- Wind tunnel/CFD studies & structural analysis
- Cable size/routing optimization (CYME®/ETAP®)
- PV system commissioning & acceptance testing
- PV performance guarantee verification testing
- Meteorological monitoring

Renewables Engineering Design

- Design criteria development
- Specification development
- Detailed cost estimates
- Grounding system design
- SCADA design & utility integration
- Heliostat/pile positioning by GPS/GNSS
- Communications system design, including SCADA/fiber optics
- AC/DC power cable sizing
- Cable routing optimization – overhead or underground
- As-built drawing services

Studies

- Irradiance studies (satellite and weather station data)
- Hydrological & geotechnical studies
- Wind data interpretation & energy yield analysis
- Meteorological mast design and installation
- Wave and weather forecasting
- Geotechnical investigations
- **Feasibility evaluations**
- **Technology evaluation/selection**

Transmission Line

AC/DC

- Route selection and evaluation
- Tower type and configuration
- Tower spotting, line design

Hits & Misses – Personal Experience

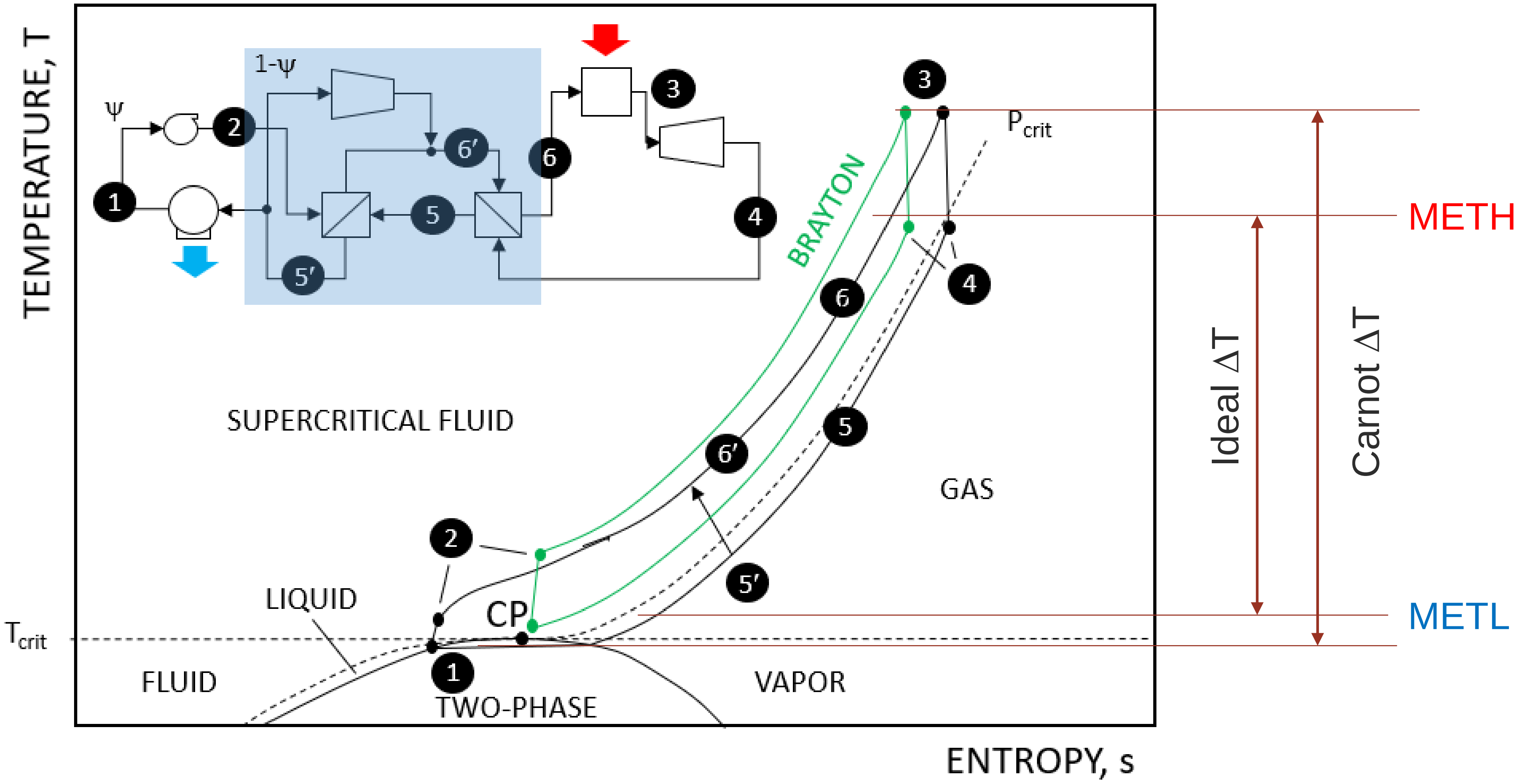
	Technical	Commercial
McIntosh, Alabama, CAES Plant (ESPC, Inc. 1994-96)	✓	✗
Cascaded Humidified Advanced Turbine (CHAT)	✗	✗
Kalina Cycle (Thermoflow, Inc., 1998)	✗	✗
H-System (General Electric, 2000-2004)	✓	✗
109FB SS-GTCC (GE, 2000-2003)	✓	✓
Duke Edwardsport 207FB IGCC (GE, 2005-2008)	✗	✗
HA Class GTCC (GE, 2008-2012)	✓	✓

sCO2 – Possible Applications

- Utility-Scale Fossil Fired Power Plant (300 – 1,000 MWe) ✗
- Utility-Scale GTCC Bottoming Cycle (400 – 1,000 MWe) ✗
- Industrial Waste Heat Recovery (< 50 MW) ✓
- Aeroderivative GT Bottoming Cycle (< 50 MW) ✓
- Gas Engine Bottoming Cycle (< 50 MW) ✓
- Small Modular Nuclear Power Plant (100 MW?) ✓
- Concentrated Solar Power Plant (100 MW?) ✓

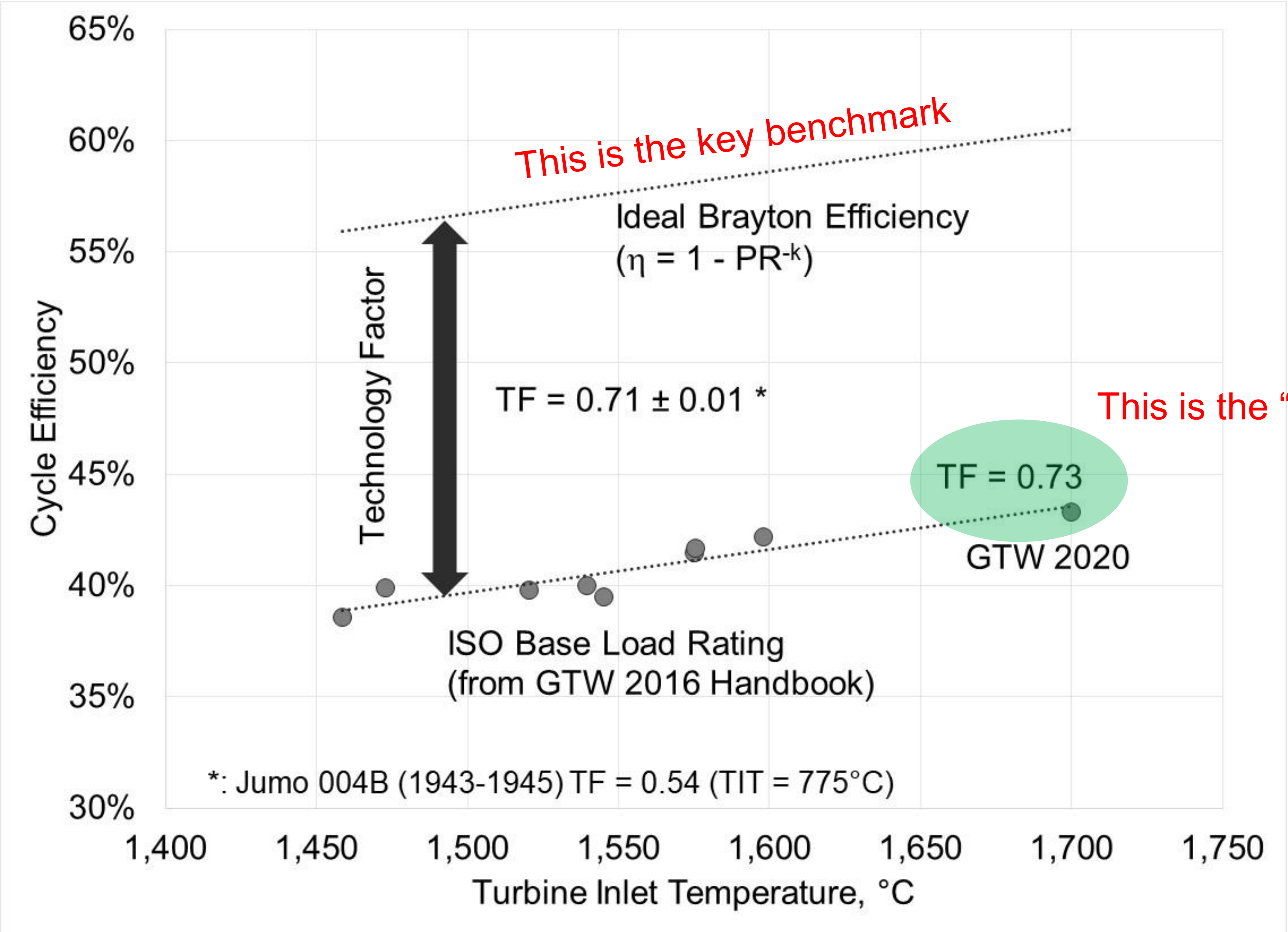
$$\text{Ideal Cycle Eff} = 1 - \psi \frac{\text{METL}}{\text{METH}}$$

Key Benchmark



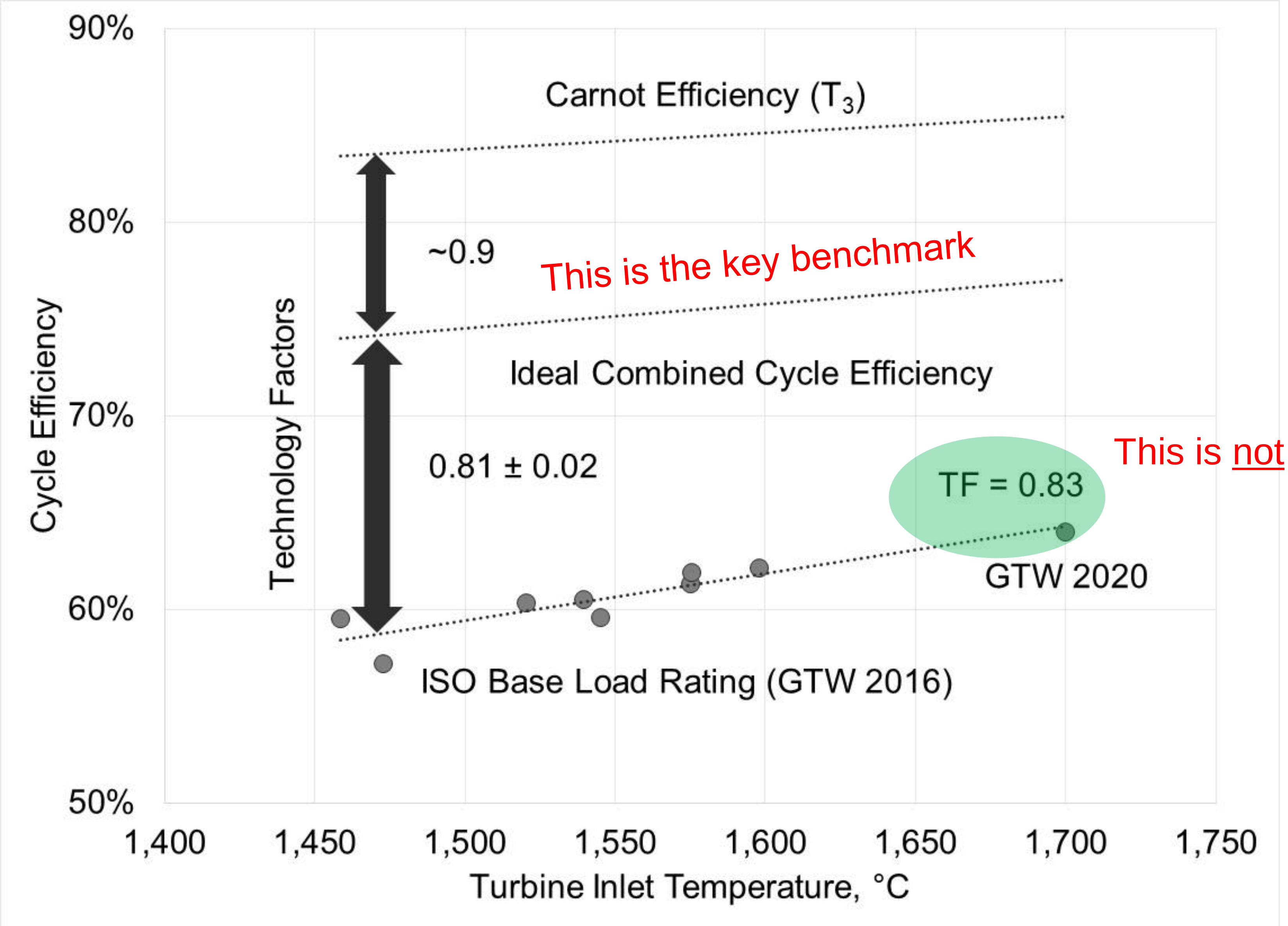
METH: Mean-effective cycle heat addition temperature
METL: mean-effective cycle heat rejection temperature

Technology Factor[1] – Gas Turbines



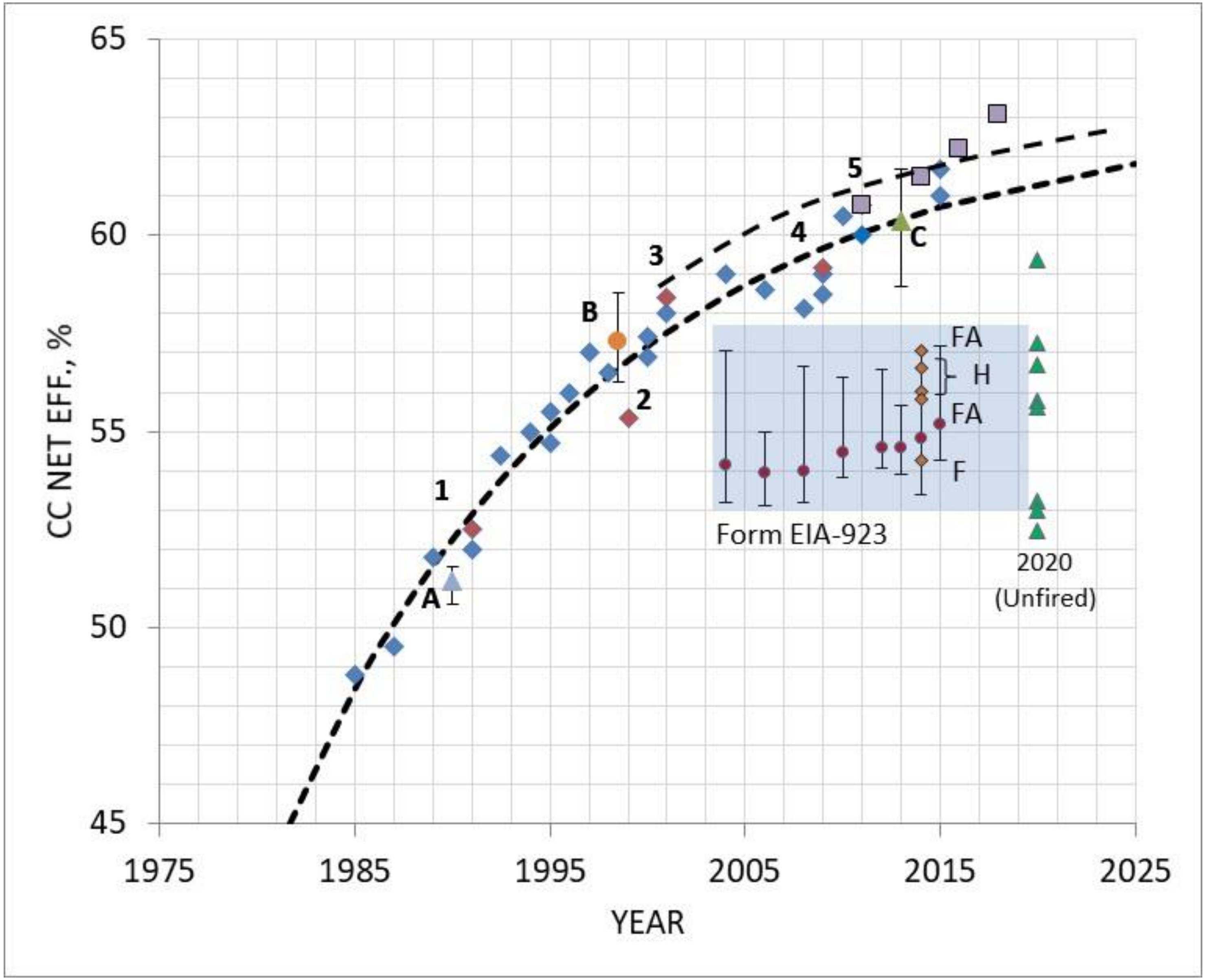
1. Gütegrad or Gütezahl in German, see *Turbo/Supercharger Compressors and Turbines for Aircraft Propulsion in WWII*, Kollmann, Douglas & Gülen, ASME Press, 2021

Technology Factor – Advanced GTCC

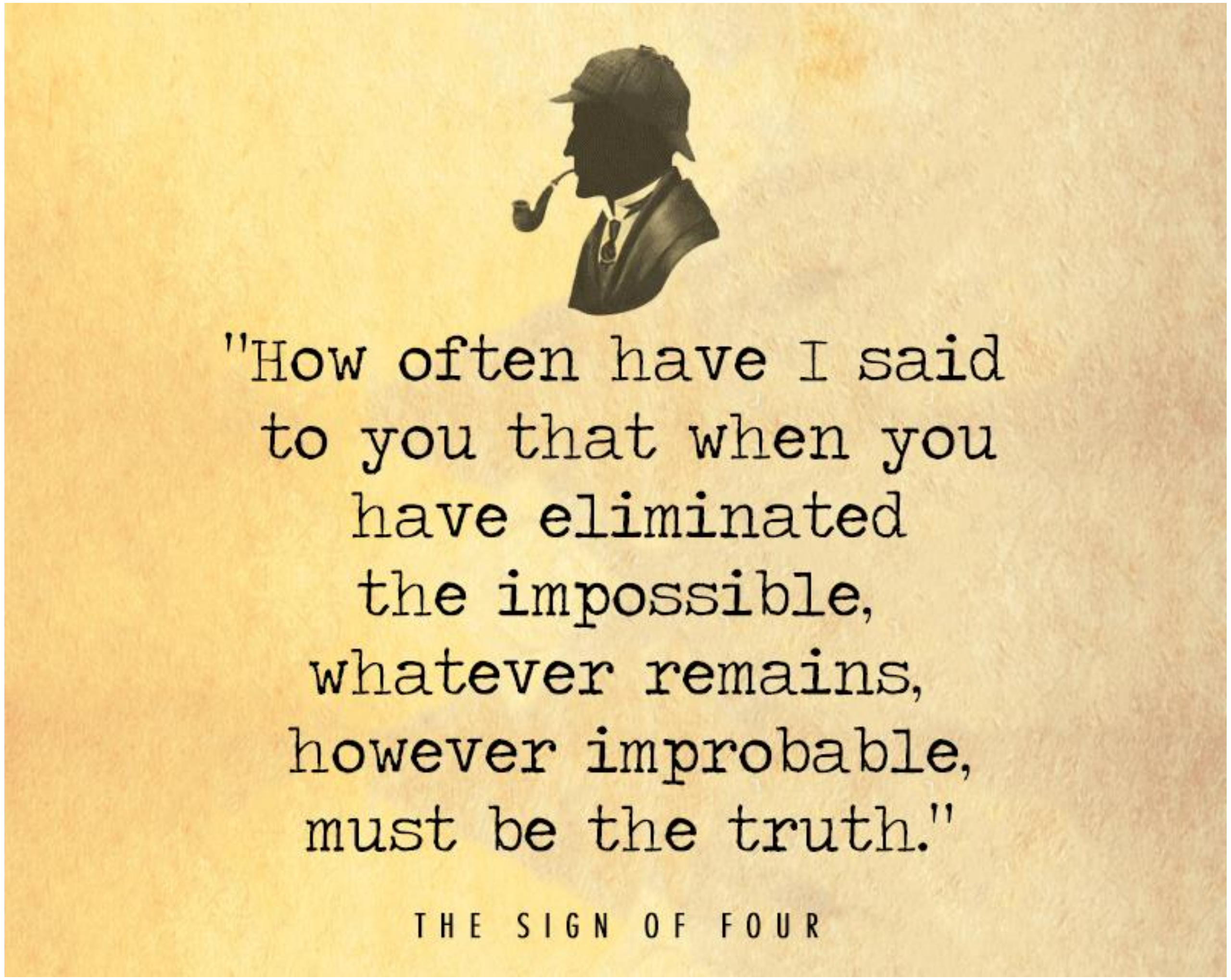


1. Gülen, S.C., *Disappearing Thermo-Economic Sanity in Gas Turbine Combined Cycle Ratings – A Critique*, ASME Paper GT2019-90883, ASME Turbo Expo 2019, June 17-21, 2018, Phoenix, AZ.

When the Rubber Hits the Road



Cut to the Chase[1]…



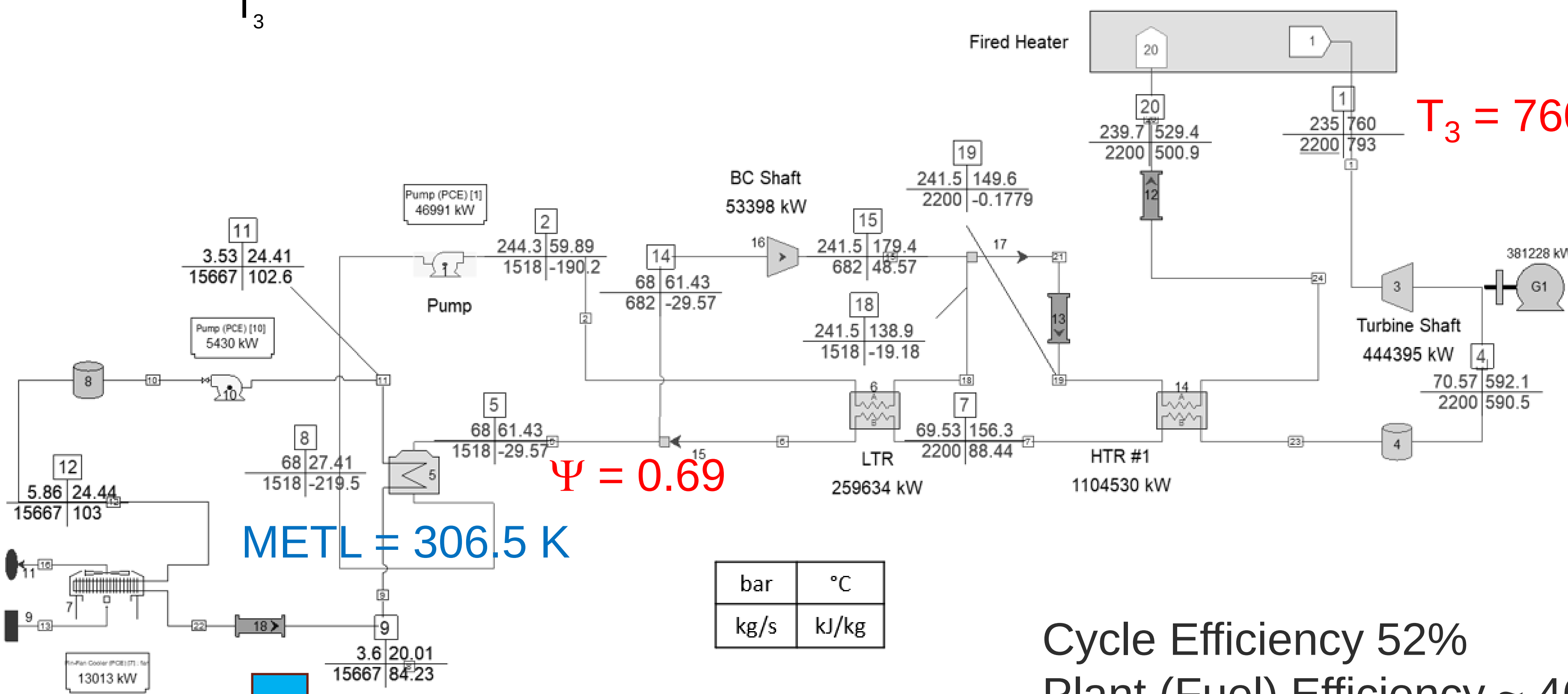
1. For the numerical examples below, see *Gas & Steam Turbine Power Plants – Applications in Sustainable Power*, S. Can Gülen, Cambridge University Press, to be published in mid-2022.

Cycle Performance Is NOT Plant Performance!

$$\text{Ideal Cycle Eff} = 1 - \psi \frac{\text{METL}}{\text{METH}} = 75.9\%$$

$$\text{Carnot Eff} = 1 - \frac{T_{amb}}{T_3} = 72.1\%$$

Cycle Heat Input ≠ Fuel Burn

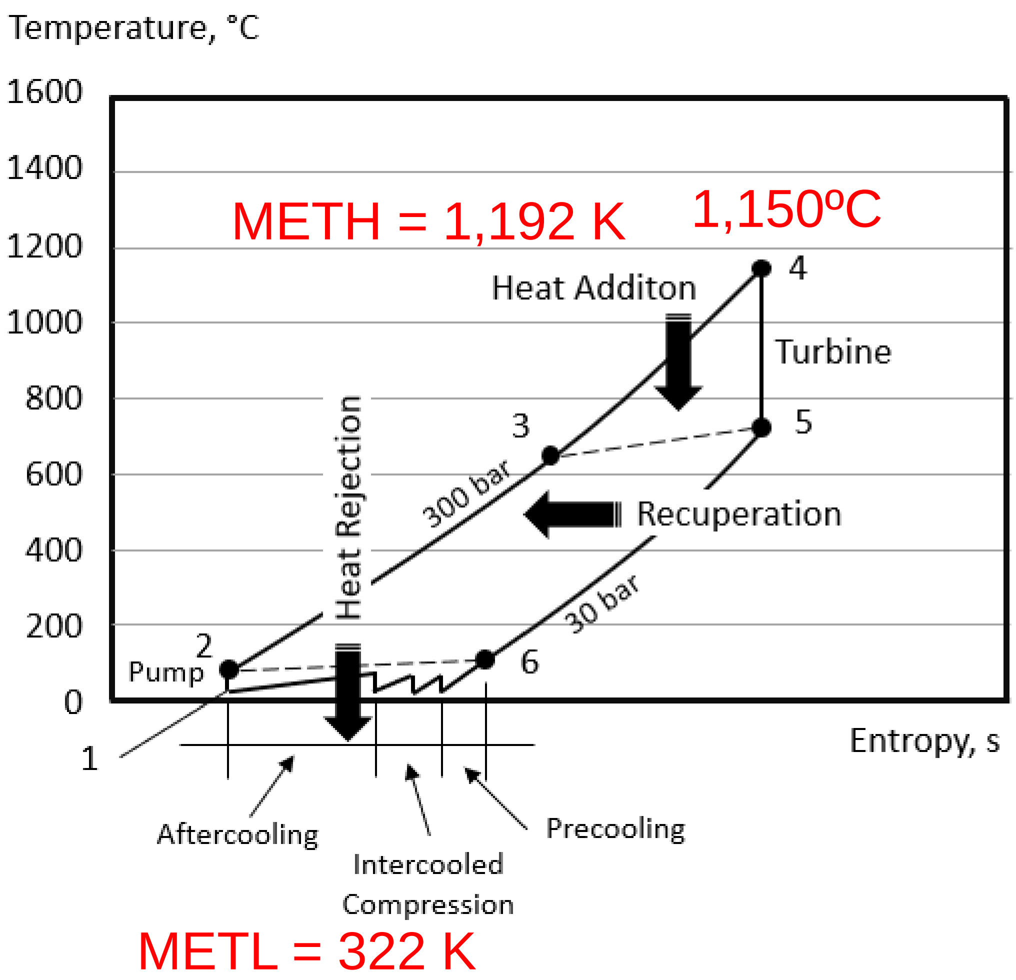


T_{amb} = 15ºC

Cycle Heat Rejection → High Parasitic Load!

Cycle Efficiency 52%
Plant (Fuel) Efficiency ~ 46%
Specific Power Output ~ 150 kJ/kg
(cf. ~ 1,200 kJ/kg SCPC)

Cycle Performance Is NOT Plant Performance!



Parasitic Power Consumers

- ASU Main Air Compressor
- O_2 Compressor
- Fuel Compressor
- Air-Cooled Condenser Fans
- Miscellaneous BOP
- Transformer Loss

Carnot Efficiency	79.8%		
Ideal Cycle Efficiency	73.0%		
Cycle Factor	0.92		
Technology Factor	0.70	0.75	0.80
Actual Cycle Efficiency	51.1%	54.7%	58.4%

Roll Over GTCC or U-SCPC? Naahh…