From non-premixed combustion in industrial furnaces to lean premixed combustion in gas turbines:

A comprehensive review, updates, and reflections on low-emission combustion applications and project management

Shanglong Zhu

26th April, 2024

Dutch Section of the Combustion Institute

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Main content

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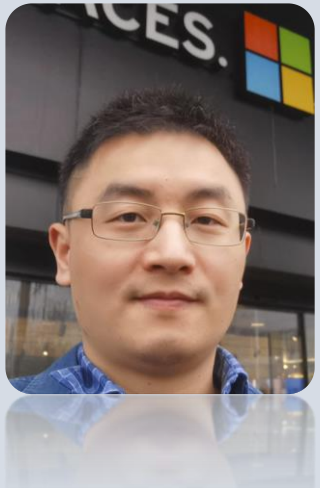
2. Non-premixed combustion in industrial furnaces
3. A brief introduction of the history of gas turbines
4. Lean premixed combustion in gas turbines
5. Reflection

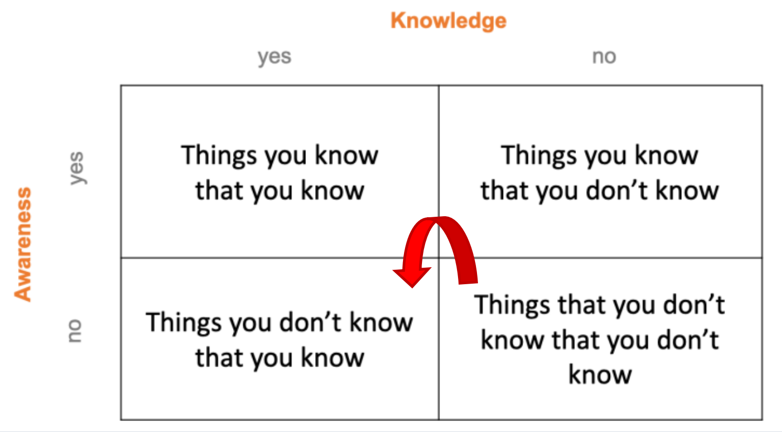
1. Self introduction



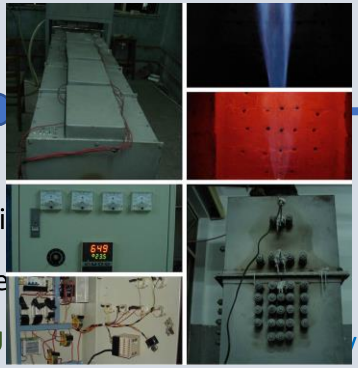
Dr. ir. MBA Shanglong Zhu

- ✓ Building Environment and Equipment Engineering (Bachelor)
- ✓ Computer Science and Technology (Bachelor)
- ✓ Thermal Engineering (Master)
- ✓ Thermal Engineering (PhD)
- ✓ EMBA
- ✓ Member of IC,ASME,IEEE,PAiE, etc.

- Since~1999, being involved in (renewable) energy field
- University (theory)→ Industry (practice)→ Academic (theory) → Industry (practice)
- R&D of gaseous, solid and liquid fuels' utilization
- Driven by needs and interest; seize opportunities to learn



Main footprint



1999		2009	2014	2020
Indoor ai	Gas+liquid fuel + solid fuel	Spray combustion	Heavy-duty gas turbine	Tech+managerial support
Compute	Coal gasification	(Exp.+Simu.+Industry)	(Sub.->System-> Mgt.)	Learn & Practice
Tianjin U	SMDERI (CSIC)	Twente+TUDelft	Ansaldo Thomassen+RSM	Longway Energy+SmartMed

CCC (Clean Combustion Concept) projects

Executed in collaboration between universities in the Netherlands and industrial partners (2009-2014)
Main sponsor: Technology Foundation STW

HiTAC – **Heavy fuel-oil** combustion in a HiTAC **boiler**

XCiDE – Crossing combustion modes in **diesel Engines**

MILDNOx – **NOx** formation and fuel flexibility in **dilute combustion**

ULRICO – Ultra **rich combustion** of **natural gas** and **soot** formation

BiOxyFuel - Torrefied **biomass** combustion under oxy fuel conditions

MoST - Multi-scale modification of **swirling combustion** for optimized **gas turbines**

ALTAS - Advanced low **NOx** **flexible fuel** gas turbine combustion, aero and stationary

FlexFLOX - **Flameless combustion** conditions and efficiency improvement of single- and multi-burner-FLOX® **furnaces** in relation to **changes in fuel and oxidizer** composition

HiTAC – Heavy fuel-oil combustion in a HiTAC boiler

Collaboration of University Twente, TU Delft, Stork Technical Services and Shell
Project leader: T.H. Van der Meer, U Twente

Laboratory experiments
Light fuel oil

Laser diagnostics to study:

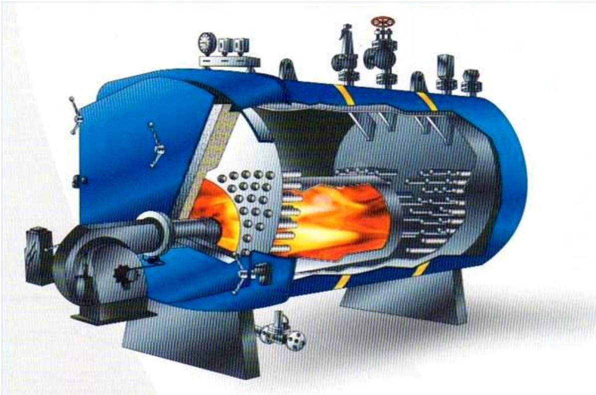
Atomization process
Ignition
Entrainment
Burnout

Providing a database for validation

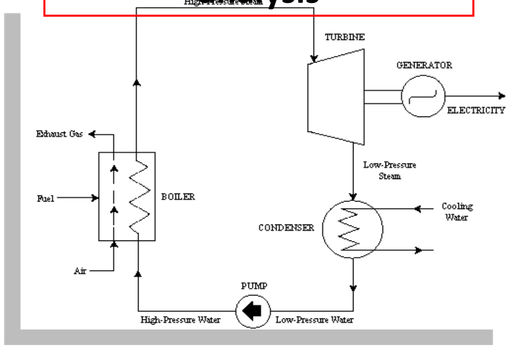
Model development and numerical simulations

Spray combustion models for
light and heavy fuel oil
Turbulence
Heat transfer
Emissions:
NOx, CO and soot

Field test
Heavy fuel oil



Water-steam cycles analysis



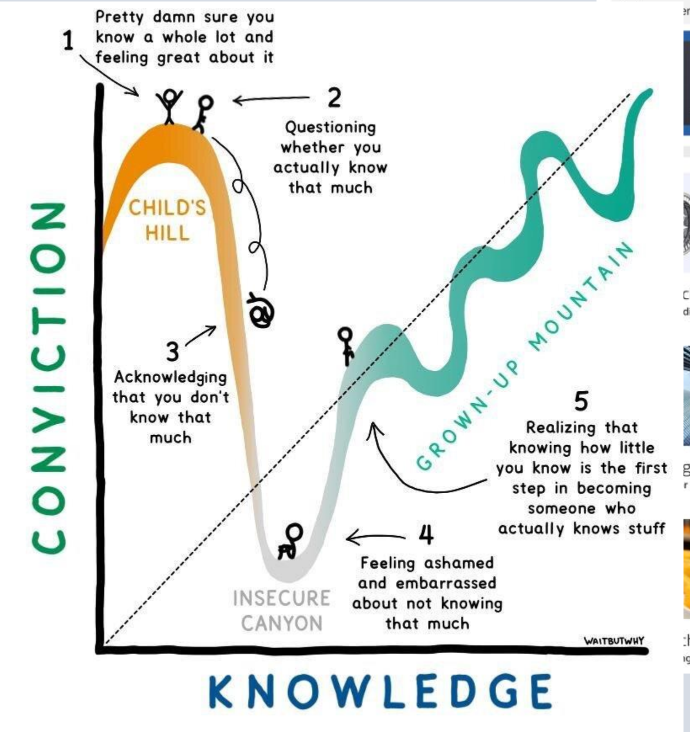
The HiTAC team

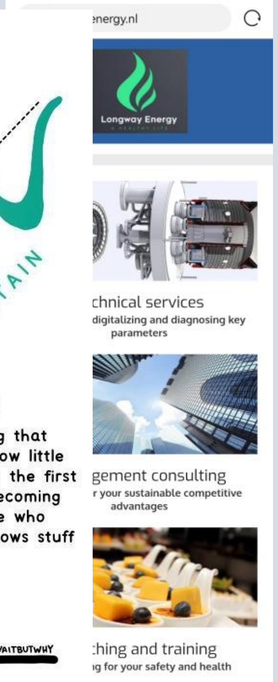
SHELL STORK® UNIVERSITEIT TWENTE. STW

Self introduction

- Since~1999, being involved in (renewable) energy fiel
- University (theory)- Industry (practice)- Academic (the
- R&D of gaseous, solid and liquid fuels' combustion
- Driven by needs and interest; seize opportunities to lea

the Dunning-Kruger Effect





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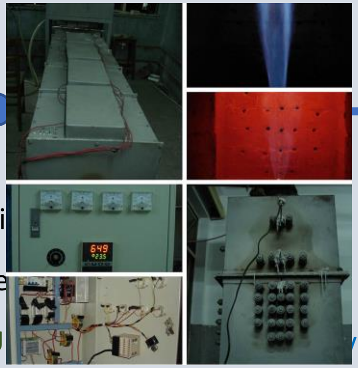
Main footprint

1999



2009

Indoor ai

Compute

Tianjin U

Gas+liquid fuel + solid fuel

Coal gasification

SMDERI (CSIC)

Spray combustion

(Exp.+Simu.+Industry)

Twente+TUDelft

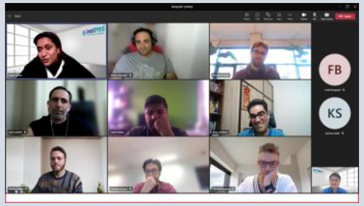
He

Ar

Tech+managerial support

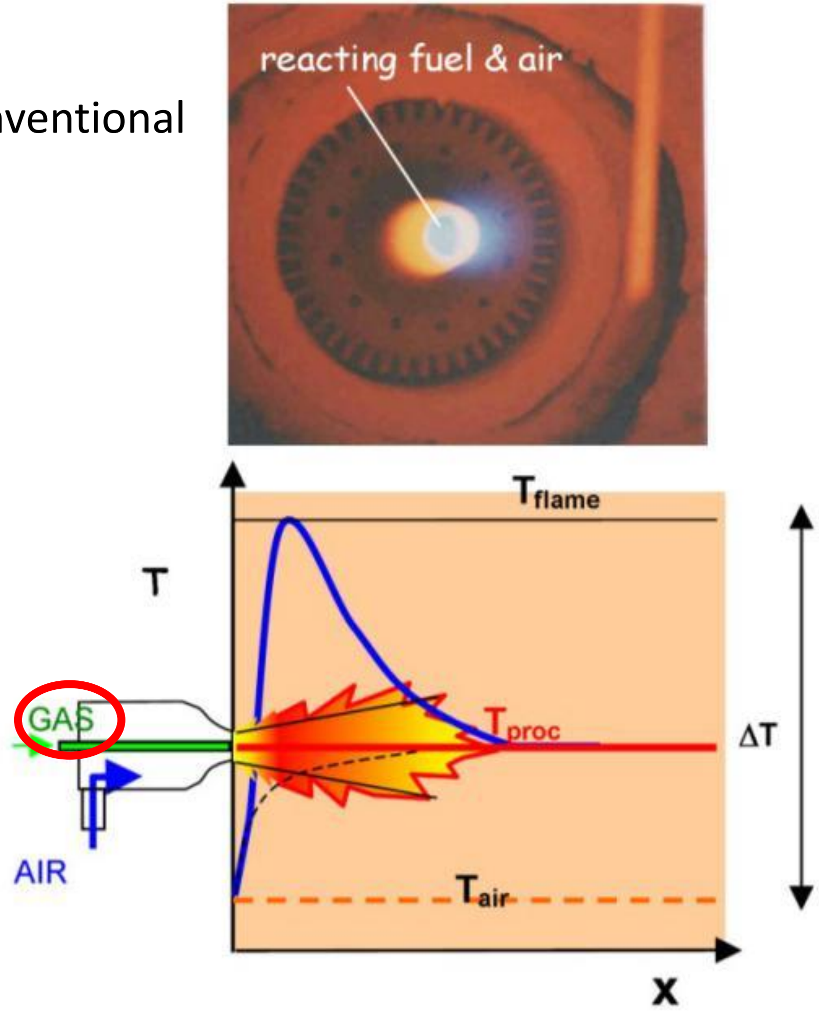
Learn & Practice

Longway Energy+SmartMed

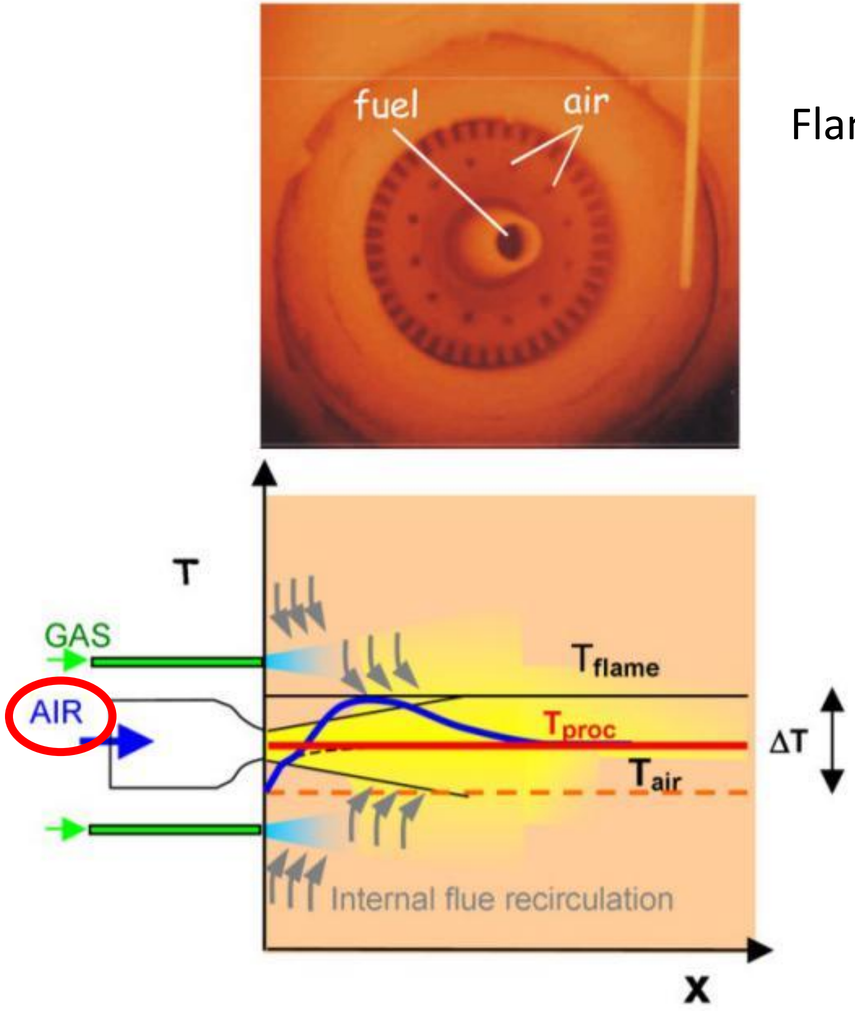


2. Non-premixed combustion in industrial furnaces– peak T vs. avg T

Conventional



Flameless/Mild/HiTAC

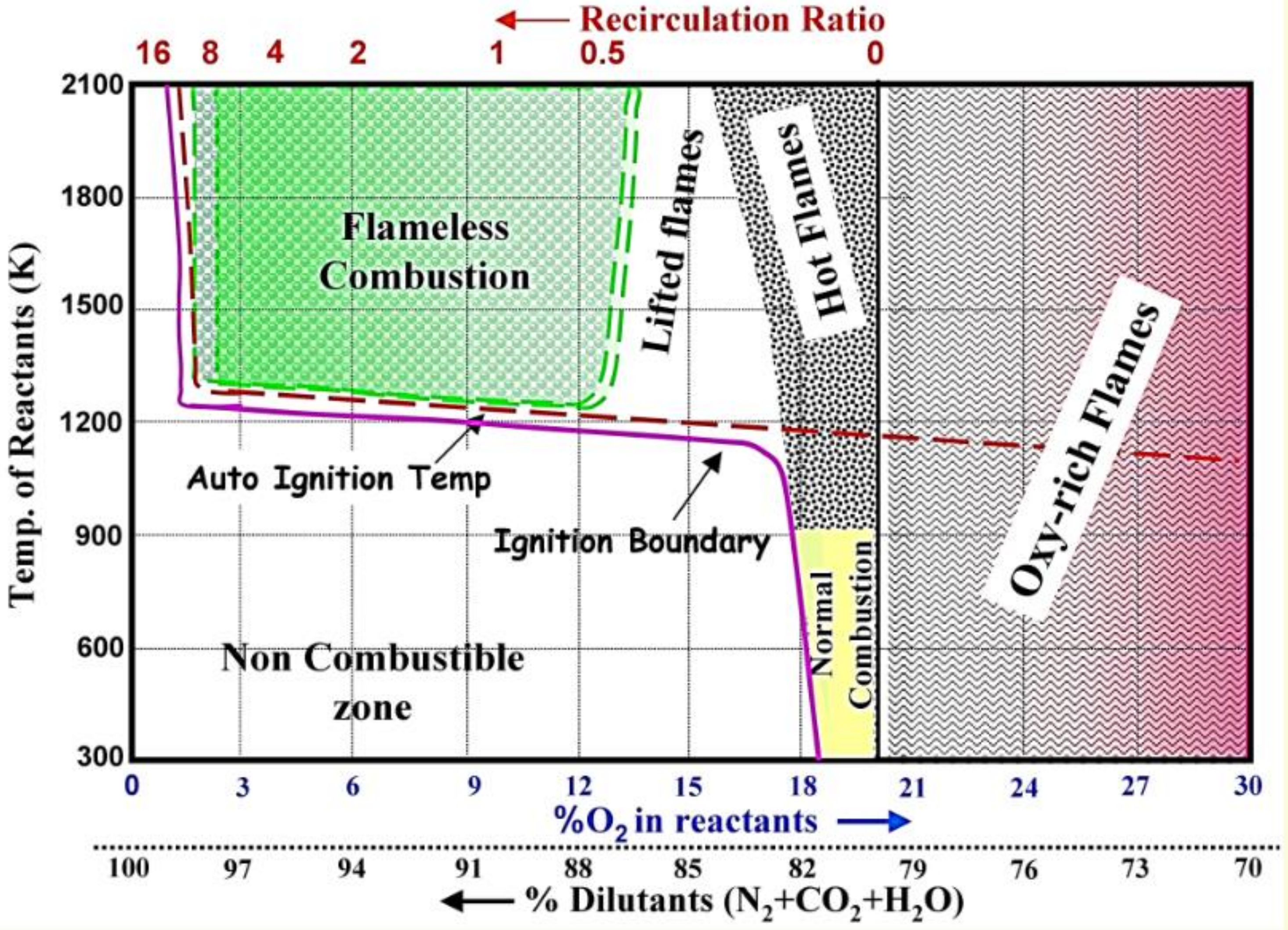


Entrained flue gas→
Low local O_2 content

(M. Khosravy el_Hossaini, Review of the new combustion technologies in modern gas turbines, Process in Gas Turbine Performance (2013): 978-953)

2. Non-premixed combustion in industrial furnaces– flame type

HiTAC test furnace for pre-reduction of Carbon-bearing Chromite Pellets

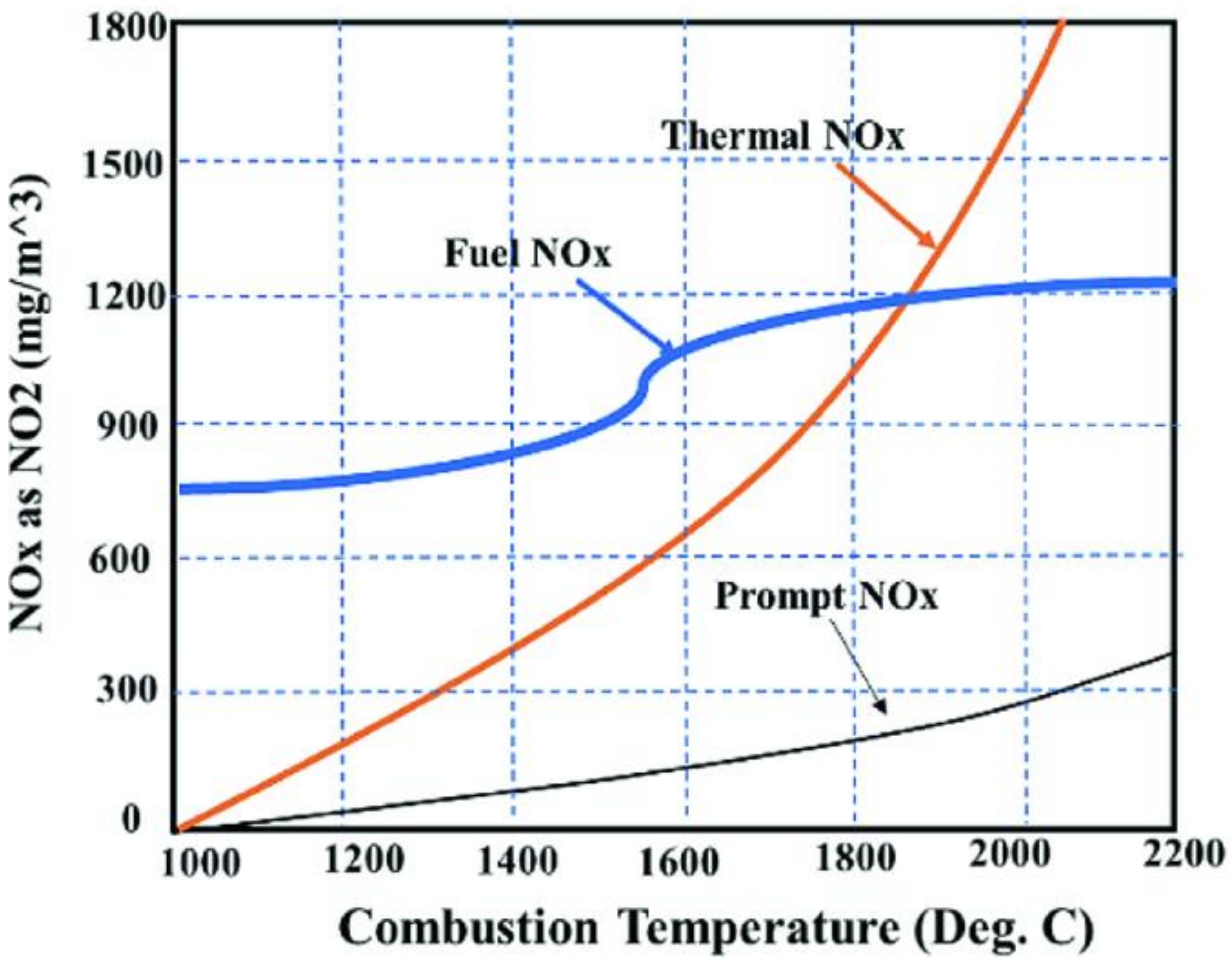


Ladle heater

(Shanglong Zhu, Xiangrong Sui, Wei Zheng, Application of Oxygen-Enriched Combustion Technology in Ladle Roaster, Industrial Furnace, 2007 Vol.29(4):21-23)

(A. G. Rao and Y. Levy, A new combustion methodology for low emission gas turbine engines, in 8th HiTAC conference (2010))

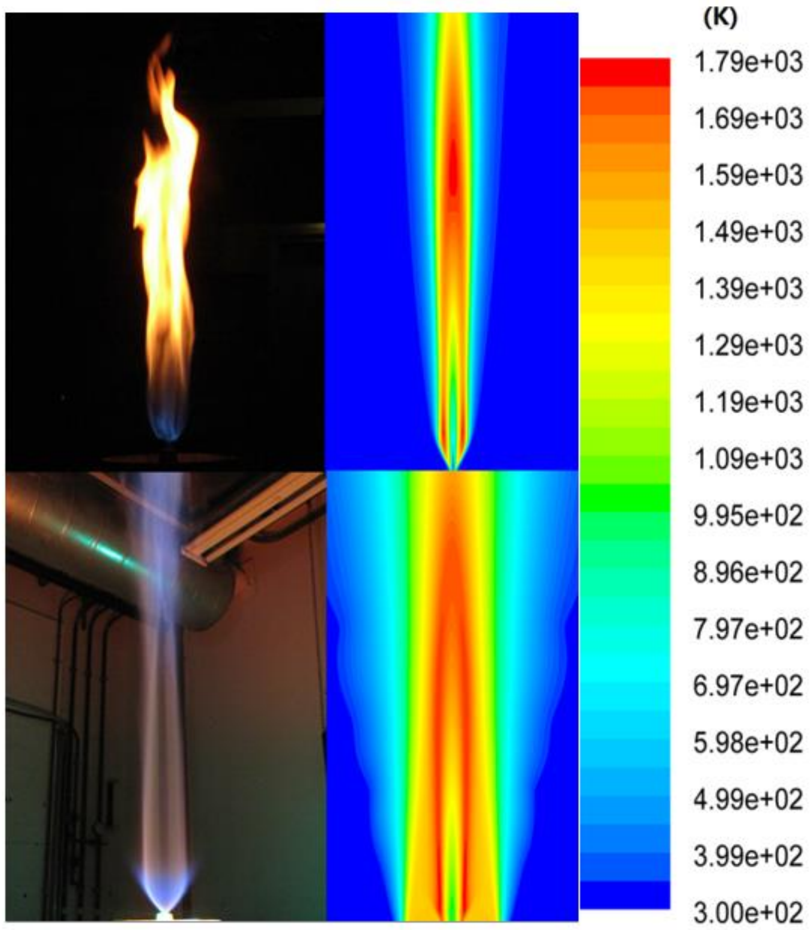
2. Non-premixed combustion in industrial furnaces-- NOx



Qualitative

(Utkarsha Sonawane & Avinash Kumar Agarwal, Novel Internal Combustion Engine Technologies for Performance Improvement and Emission Reduction,15 June 2021, pp 197–220)

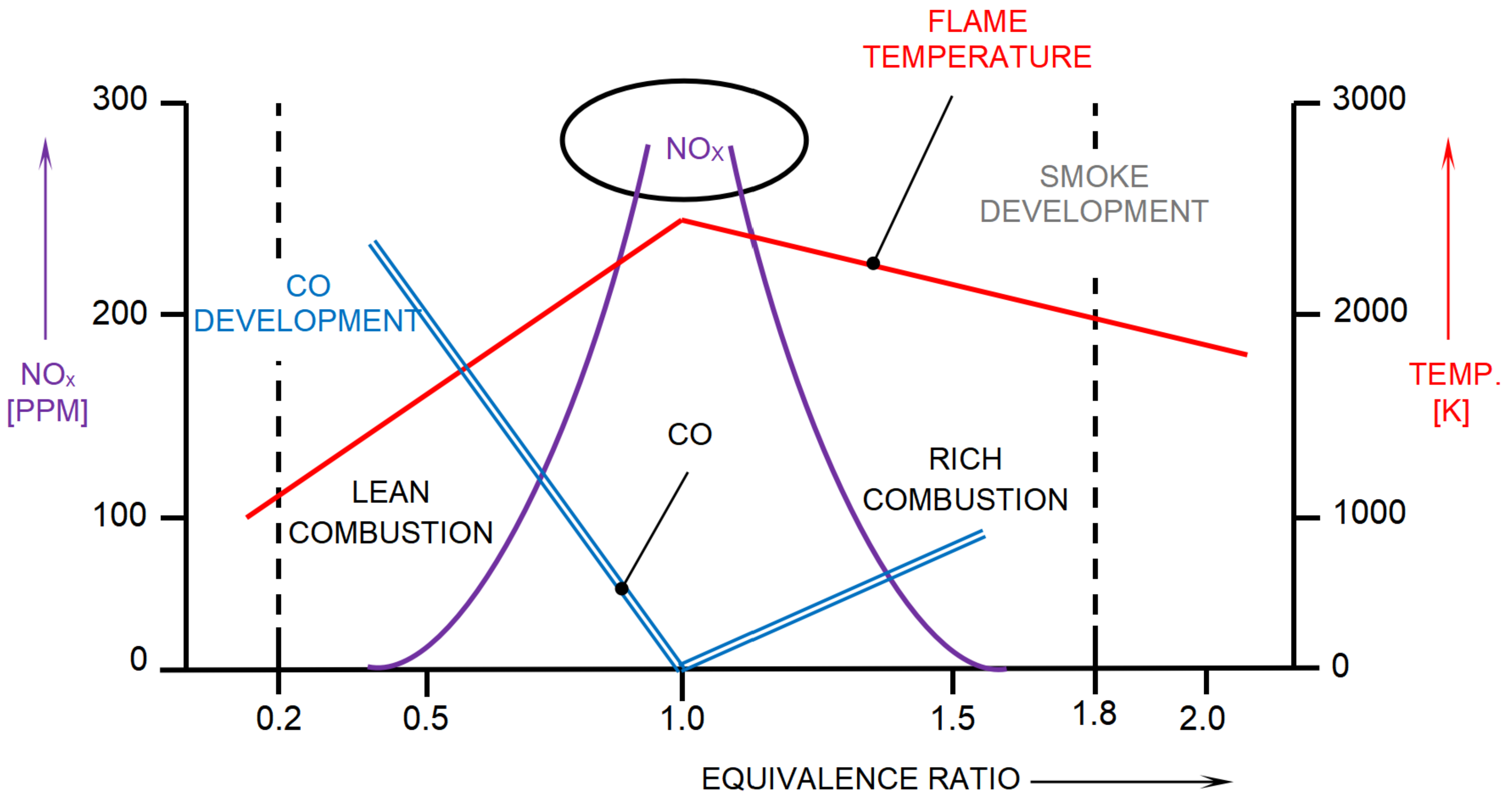
2. Non-premixed combustion in industrial furnaces– liquid fuel



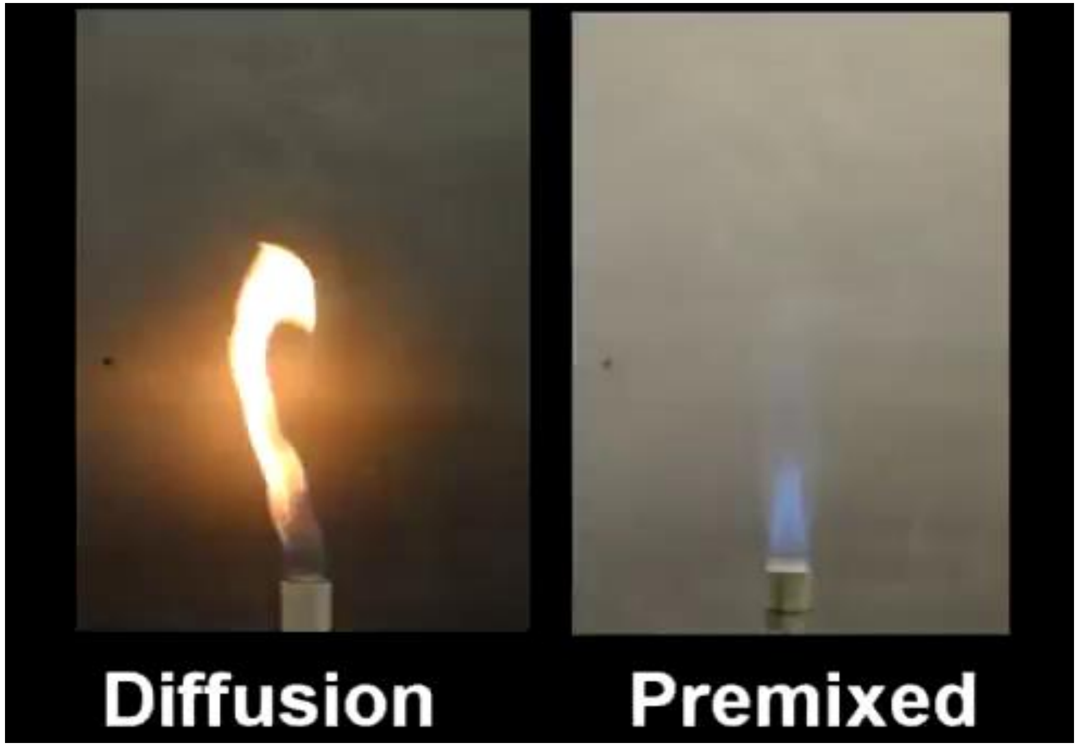
Experimental (left) and numerical (right) results from ethanol combustion in cold co-flow (top) and hot co-flow (bottom)

(Shanglong Zhu, Artur Pozarlik, Dirk Roekaerts, Hugo Correia Rodrigues, Theo van der Meer, Numerical investigation towards HiTAC conditions in laboratory-scale ethanol spray combustion, Fuel, Vol. 211, 1 January 2018, pp 375-389)

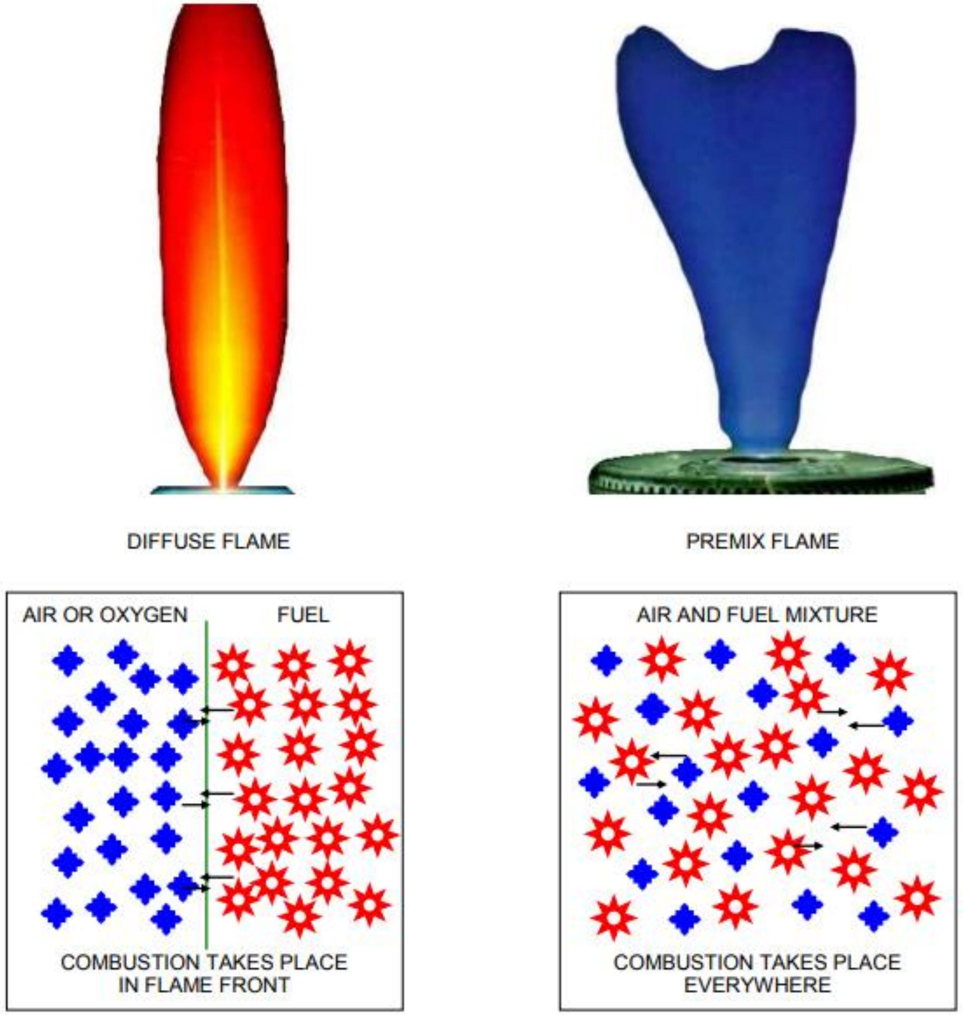
2. Non-premixed combustion in industrial furnaces–T, NOx, CO, HC



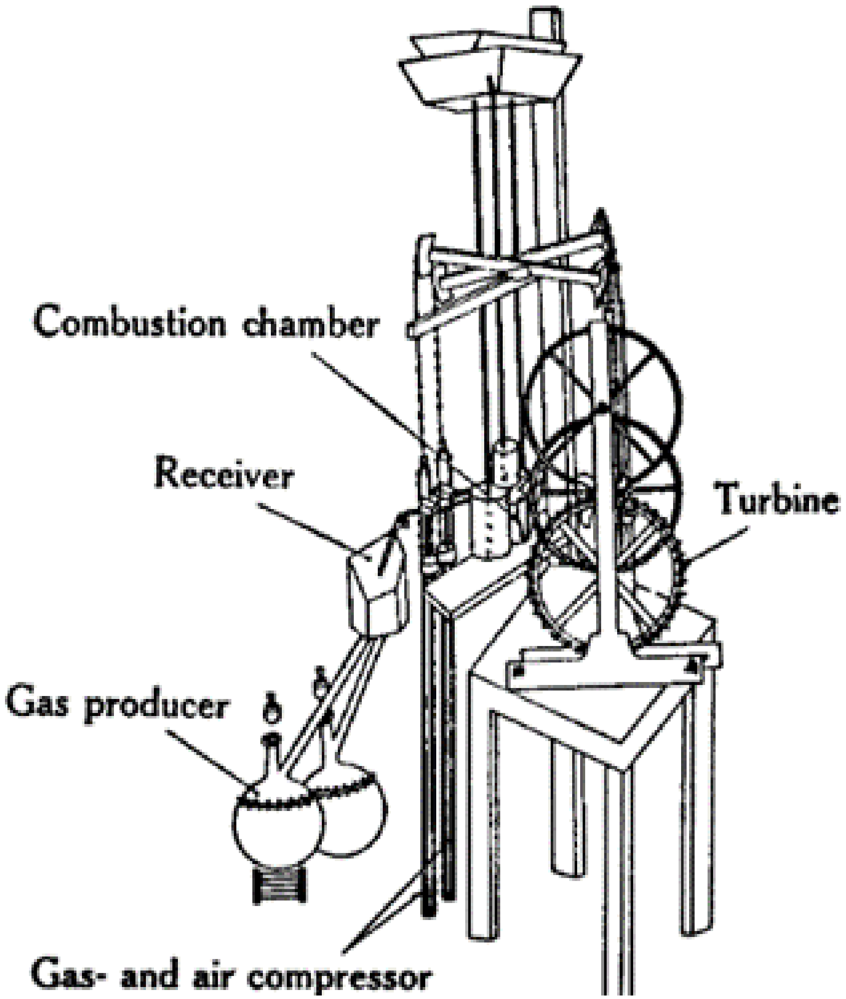
2. Non-premixed combustion in industrial furnaces– diffusion vs. premixed



In gas turbine industry, premixed combustion is widely used to reduce NOx emissions

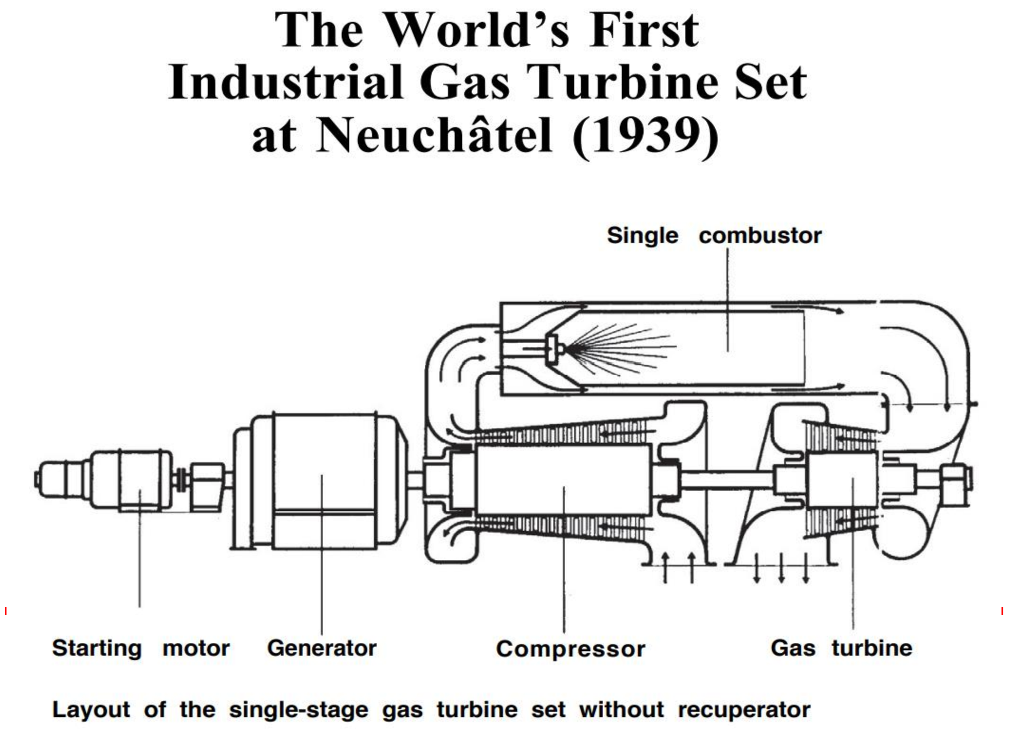


3. A brief introduction of the history of gas turbines

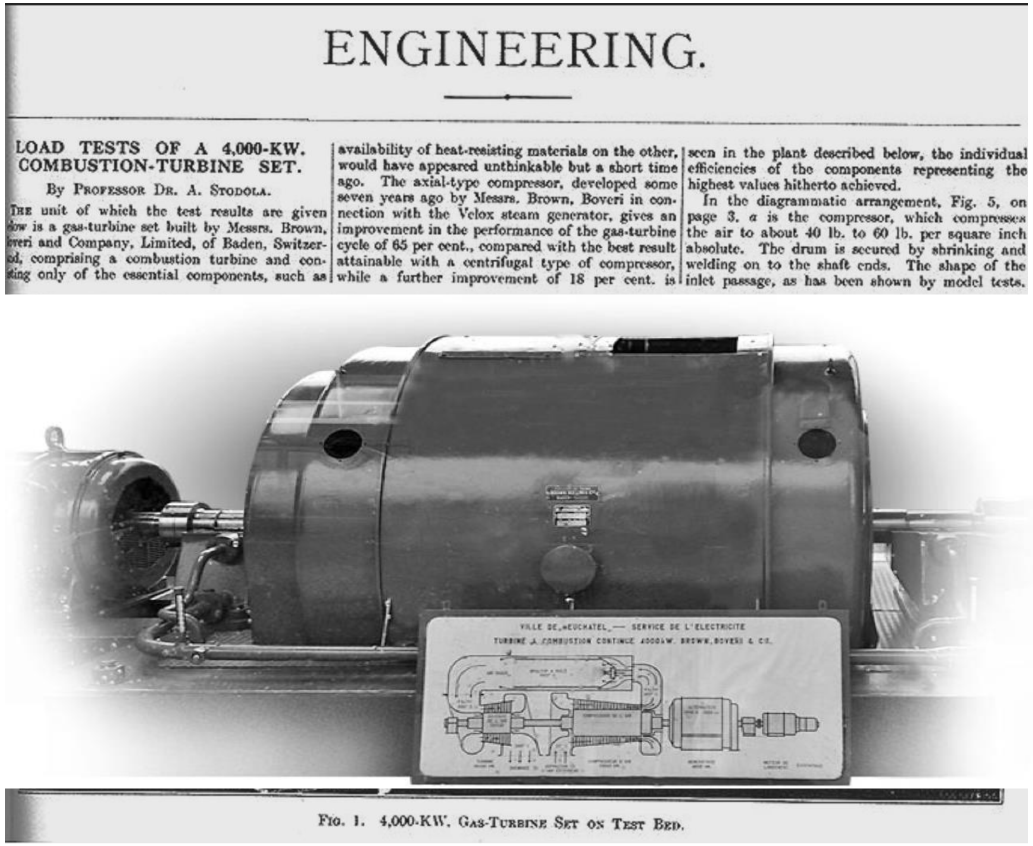


(1791, John Barber, UK)

- 1791, **John Barber** introduced a design of GT;
- In 19^{th} century, GT was under development, but **no product yet**;
- In 1900, **Carnot**, **Gibbs** and **Maxwell** established the laws of thermodynamics;
- In 1939, **Brown Boveri Corporation** designed, manufactured and operated the first industrial GT.

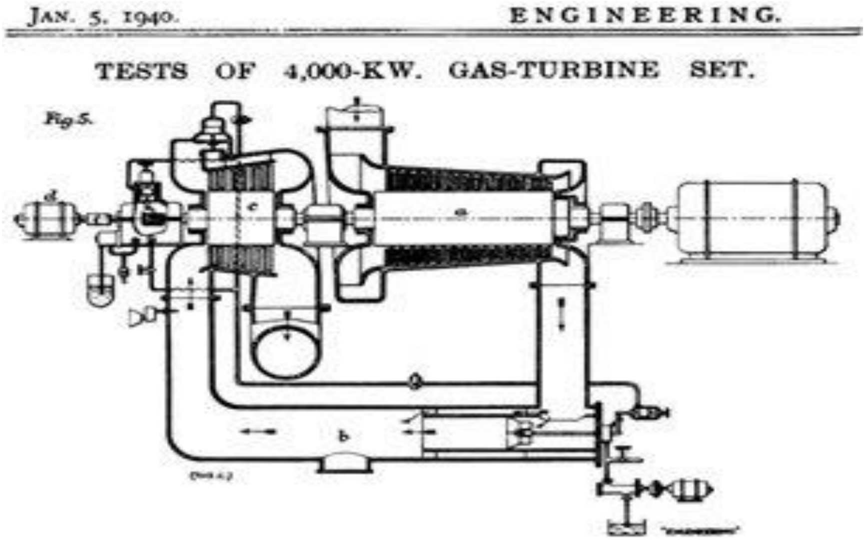


3. A brief introduction of the history of gas turbines-- ABB



(1939, **Brown Boveri Corporation** designed and manufactured the world' s first industrial GT)

- **Brown Boveri Corporation**) : founded by Charles **Brown**(UK) and Walter **Boveri** (Germany) in 1891, and headquartered in Baden, Switzerland;



- In January 1988, **Brown Boveri** merged with **ASEA** to form **Asea Brown Boveri** (**ABB**). Headquartered in Zurich, Switzerland; Asbestos case
- From 1998, ABB started to sell its main power generation business to **Alstom**.

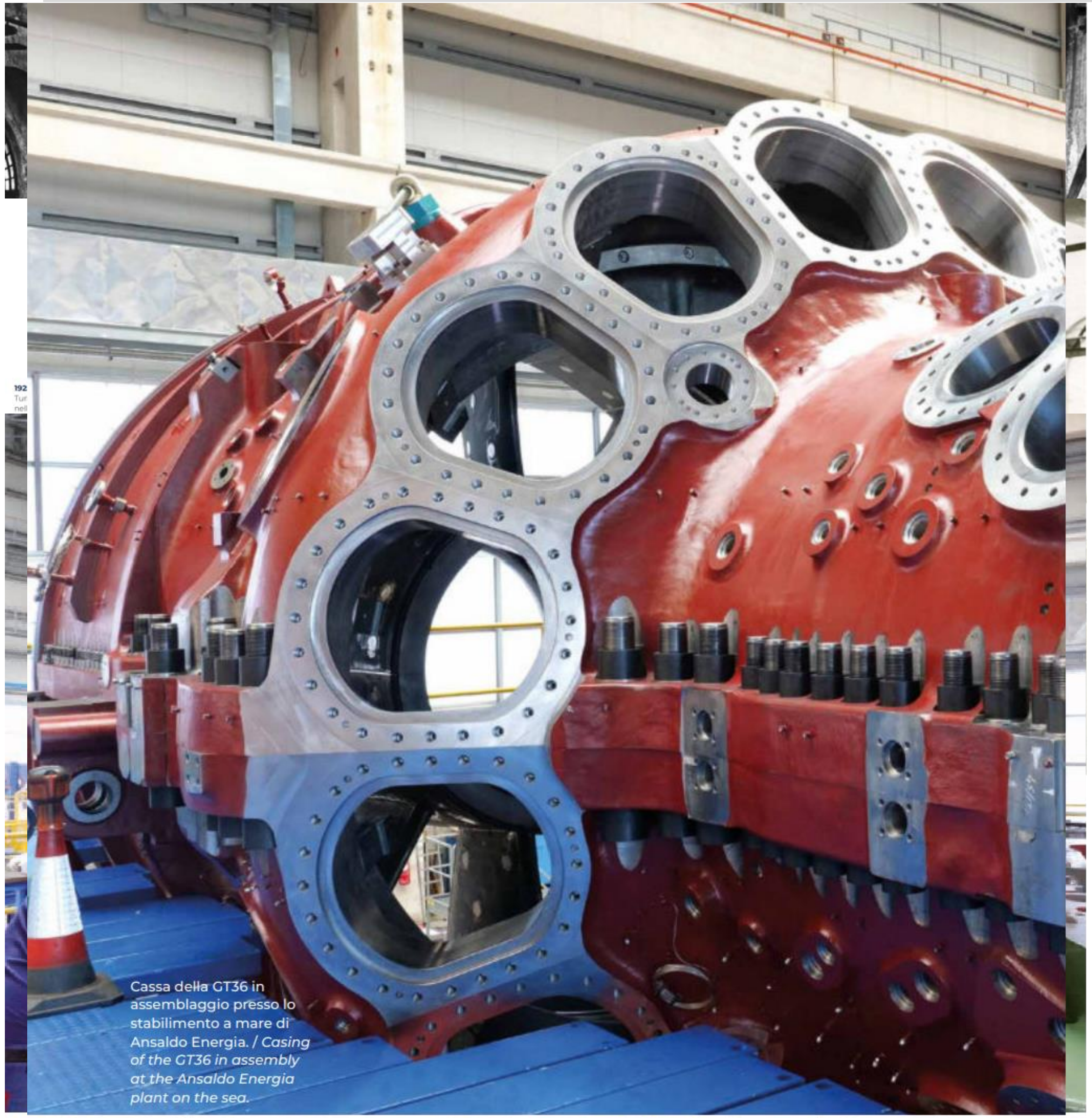
3. A brief introduction of the history of gas turbines-- Alstom

- In 1928, **Alsthom** was established in France by the merger between the electric engineering division of Société Alsacienne de Constructions Mécaniques (**Als**) and Compagnie Française Thomson-Houston (**thom**), with its headquarters in Paris;
- In 1932, acquired Electricite de France; in 1976, acquired Atlantic Shipyard; in the late 1980s, acquired part of Belgium's ACEC;
- In 1989, a merger with parts of the British General Electric Company formed GEC Alsthom;
- **In 1998**, Alstom was listed on the Paris Stock Exchange and changed its name to **Alstom** in the same year.

3. A brief introduction of the history of gas turbines-- Alstom

- In 1999, to compete with GE, **Alstom and ABB** formed joint venture APP, and developed the **GT24** and **GT26** gas turbine generator sets with the largest power (240,000 kilowatts) and the highest design efficiency (54%) in the world at that time;
- In 2000, Alstom acquires all shares in the power generation business from ABB; Design accident
- From 2003, **financial difficulties**;
- In 2013, the United States arrested Alstom Vice President **Pierucci**. GE and Siemens bid for Alstom;
- In 2015, GE's acquisition of the power and grid sector was obtained, after Alstom sold its heavy-duty gas turbine business (GT26&GT36 and US Power System Manufacturing PSM Company) to **Ansaldo Energia**.
- In 2021, Ansaldo Energy sold its **Ansaldo Thomassen** and **PSM** to Hanwha Group (South Korean).

3. A brief introduction of the history of gas turbines-- Ansaldo

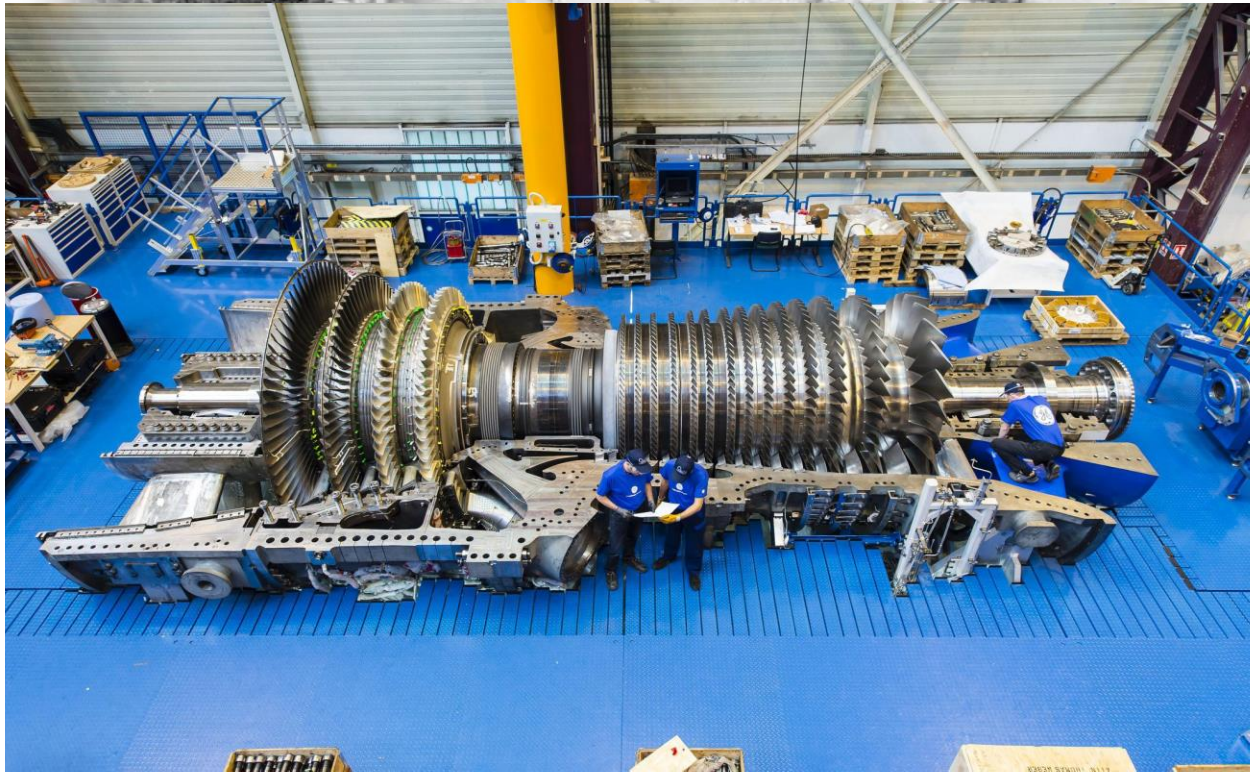


GT36 gas turbine assembly

- In1853, Ansaldo was founded in Genova, Italy;
- Business after the acquisition of ATH and PSM in 2014:
  - **GE** Frame 5 6B 9E
  - **Alstom** GT26/36
  - **AE** V94.2, 64.3, 94.3
  - **Mitsubishi** 501F 701F GE 6F 9F etc.

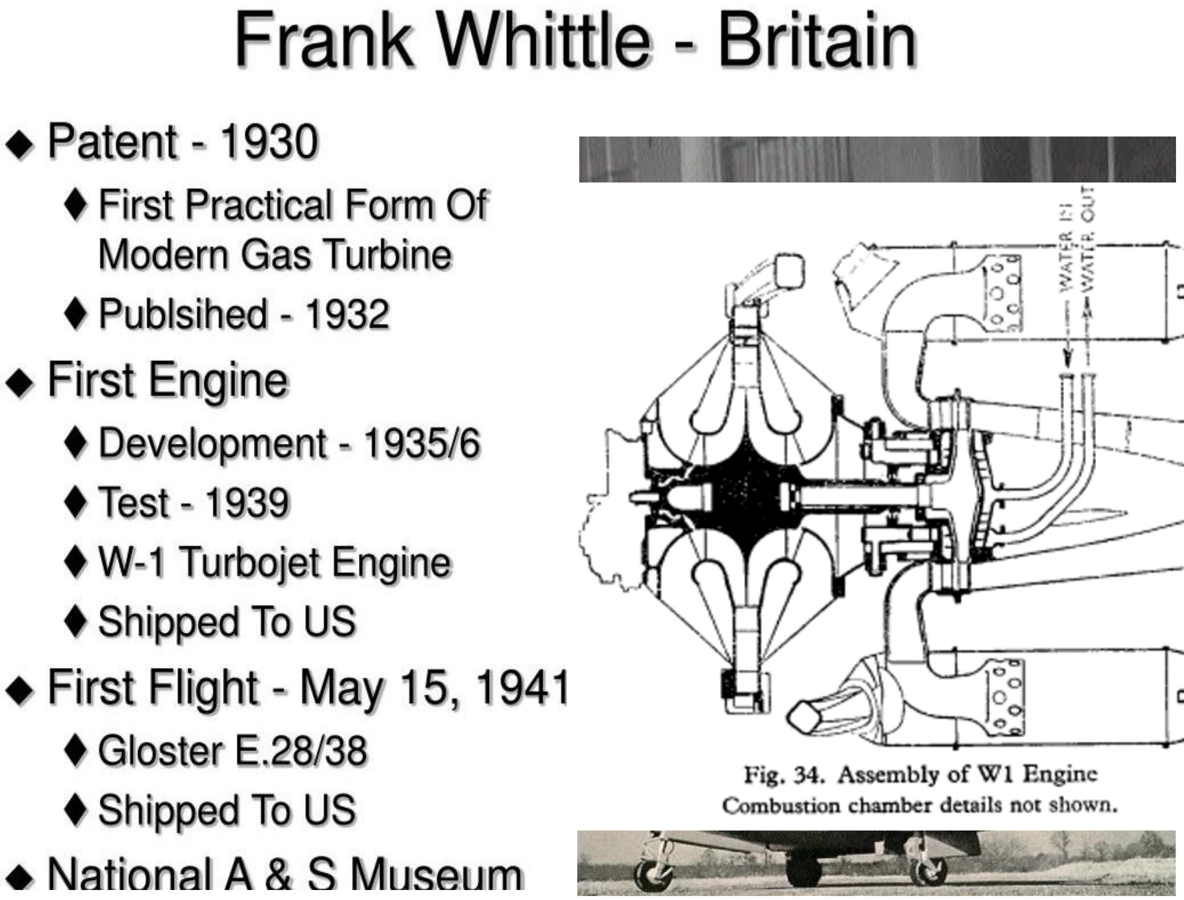
Type	ISO power (MW)		Frequency (Hz)
	Simple cycle	Combined cycle (depending on configuration)	
GT36-S5	560+ (43.0%)	760÷1,525	50
GT26	370 (41.0%)	540÷1,083	50
AE94.3A	340 (40.3%)	495÷992	50
AE94.2	191 (36.8%)	287÷578	50
AE64.3A	80 (36.4%)	120÷243	50/60

3. A brief introduction of the history of gas turbines-- GE



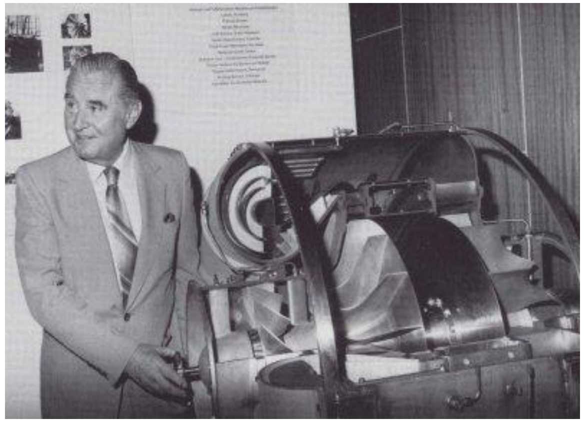
- In 1949, the world's first gas turbine for power generation was put into commercial operation at the power station in Bell Island, Oklahoma, USA. This **Frame3** gas turbine was designed and manufactured by GE, with an output of 3.5MW (actually larger);
- In 1951, the two-shaft intercooled regenerative gas turbine was introduced;
- In 1953, the first reheated intercooled regenerative gas turbine was put into commercial use;
- In 1960, the first CCGT station was put into commercial use;
- In 1968, the first LM light GT was introduced (J79 aeroengine → LM1500);
- In 1969, LM2500;
- In 1970, the Frame5 and Frame7 series came out, and GE cooperated with Alstom to develop the Frame9 single-shaft gas engine (BBC launched GT11 and GT13 at the same time);
- In 1971, the first E-class (7E) gas turbine was unveiled;
- In 1972, Frame7B (51.8MW) came out;
- In 1975, Frame9B (80.7MW) came out;
- In 1978, the first 6B-class gas turbine came out (DLN was introduced in 1991);
- In 1988, LM6000 came out;
- In 1990, the first 7F was put into operation (in the same period, Westinghouse cooperated with Mitsubishi to launch the 501F gas turbine in 1989;
- Siemens launched the V94.3 gas turbine in 1991; ABB launched the GT24 at the end of 1991 (60 Hz)/GT26 (50 Hz) gas turbine);
- In 1992, the first 9F gas turbine came out;
- In 2003, GE released its first 9H-class gas turbine;
- In 2005, Frame 6C came out;
- In 2014, GE launched **HA-class gas turbines**. Turbine vapor cooling OUT

3. A brief introduction of the history of gas turbines– aeroengine

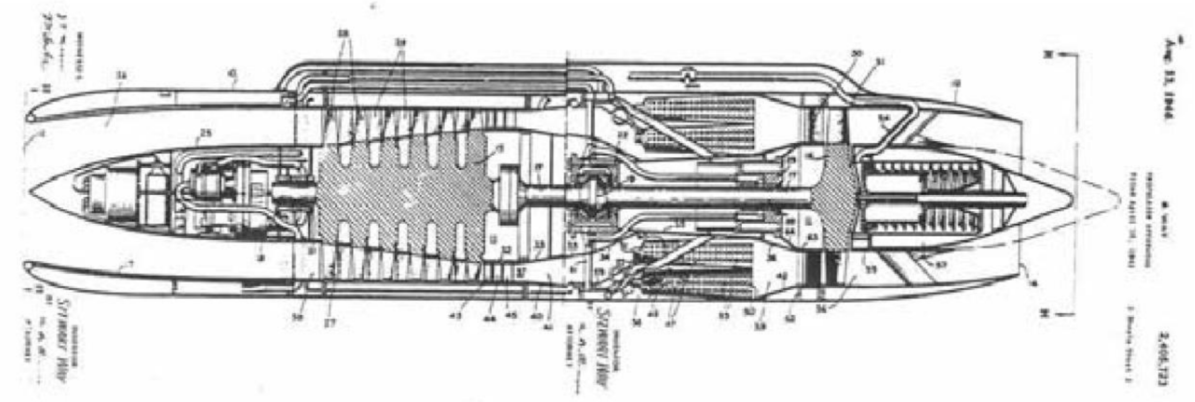


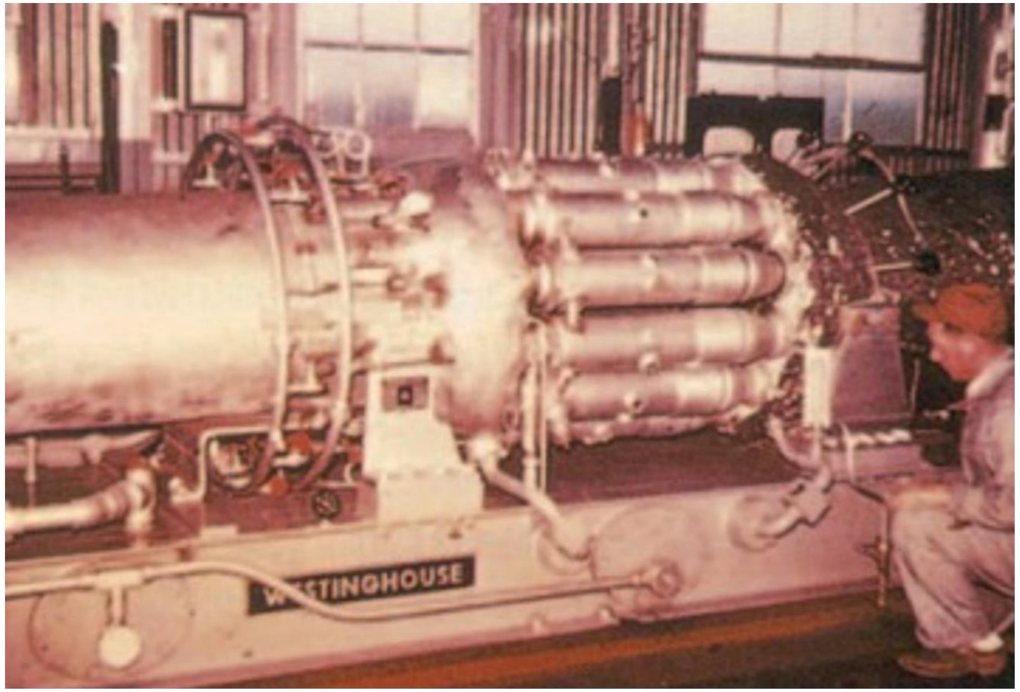
(RAE, Frank Whittle)
(in 1941, first flight of Glouster E28/39, powered by W-1)

- In 1930, **Frank Whittle** (British) registered a patent, and the W-1 gas turbine/engine first flew in 1941;
- In 1937, the first test device by German **Hans von Ohain** ran on externally supplied hydrogen, later developed to power the world's first flyable all-jet aircraft, the Heinkel He 178 (He 178 V1) in August 1939;
- **Ernst Heinrich Heinkel**, a famous German aircraft designer and manufacturer. The He-111, which first flew in 1935, became the main bomber of the Luftwaffe.
- In 1935, he cooperated with rocket expert von Braun and began to develop rockets.



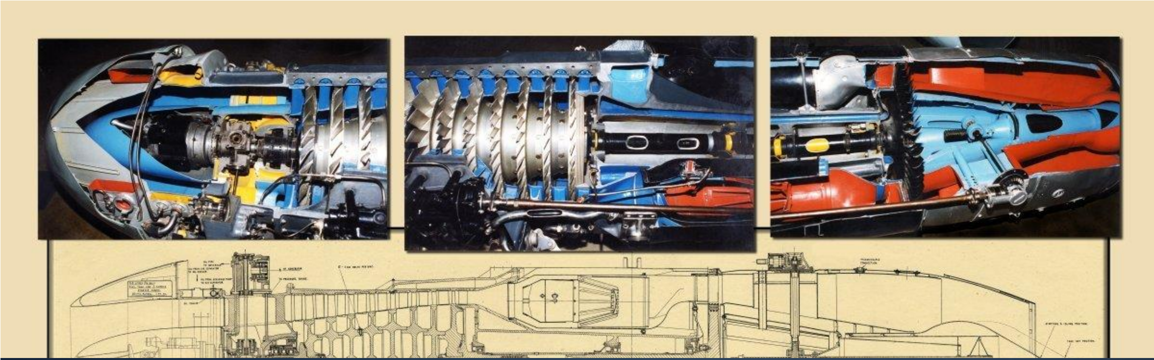
3. A brief introduction of the history of gas turbines-- Westinghouse

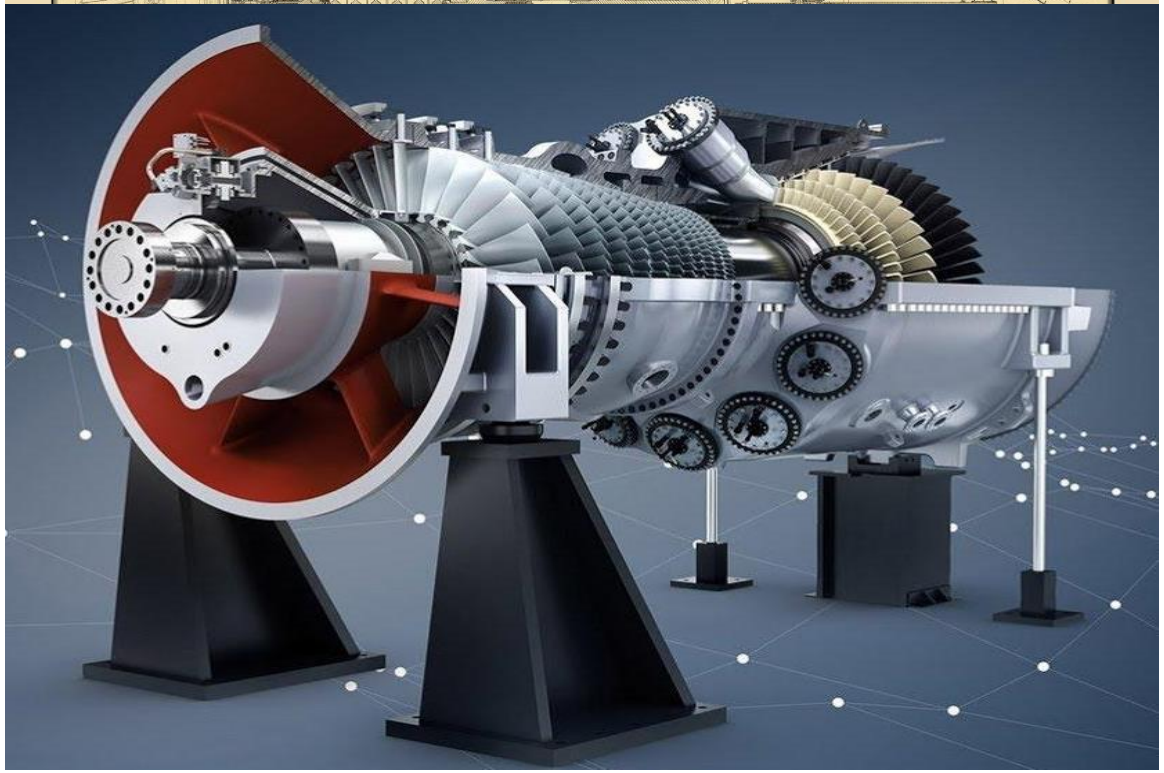




- In the early 1940s, the American Westinghouse Electric Corporation (founded in 1886) began theoretical research on aeroengines and gas turbines;
- In 1942, Westinghouse received a contract from the U.S. military for two X19 engines;
- In 1943, its first aero engine, **WE19A**, began testing -> WE19B;
- 1944, J30 (FH-1 fighter);
- In 1945, Westinghouse began to design and develop industrial gas turbines based on its J30 experience;
- In 1948, Westinghouse's first industrial gas turbine **W21** (2000 horsepower, single shaft) was launched;
- In 1952, W81 came out (5.7MW, 21% efficiency) -> W201, W31 (2.2MW), W121 (9MW) -> W171, W191 (18MW);
- In 1954, the first 3600rpm gas turbine W201 came out (18MW);
- 1968, W501 (45MW);
- 1976, W501D5 (95MW);
- 1981, W501D5 (107MW);
- 1993, **W501F** (160MW, using 3D computer code);
- 1995, W501D5A (118MW);
- In 1998, **Westinghouse** was acquired by **Siemens**;
- W501F→SGT6-5000F; W501G→SGT6-6000G.

3. A brief introduction of the history of gas turbines-- Siemens





- In 1847, **Werner von Siemens** founded the company;
- In 1942, the **JUMO 004** aircraft engine designed under the leadership of Anselm Franz made its first flight and became the first mass-produced aircraft engine (the turbine was based on the steam turbine technology of Berlin-based AEG Company). He himself immigrated to the United States after World War II, but in 1948 group member Rudolph Friedrich stayed in Germany to work on gas turbines at the Siemens factory;
- In 1948, Siemens began to get involved in gas turbines, but was limited to theoretical research due to restrictions;
- In 1950, Siemens was approved to develop gas turbines and developed **VM1** (1.5MW) and VM3 (2.8MW, efficiency 26%) based on JUMO 004;
- In 1956, the development of VM5 (5.6MW, efficiency 29%, 1956-1998) began;
- In 1962, VM80 was put into operation (23.4MW, efficiency 32%);
- In 1969, Siemens cooperated with AEG to establish KWU and acquired it entirely in 1977;
- In the 1970s, Siemens developed the V94.2 and V84.2 gas engines (symmetrical two combustion chambers); →V94.3 (SGT5-4000F); V84.3 (SGT6-4000F) and V64.3;
- After acquiring Westinghouse in 1998, SGT5-8000H (340MW; multi-tube) was developed;
- In 2017, **SGT5-9000HL** (545MW), **SGT6-9000HL** (374MW) and **SGT5-8000HL** (453MW) were launched.

3. A brief introduction of the history of gas turbines-- Mitsubishi

- In 1948, Westinghouse's first industrial gas turbine **W21** (2000 horsepower, single shaft) was launched;
- In 1963, Mitsubishi Heavy Industries purchased the patent license from Westinghouse and manufactured the first 730°C rated **MW-171** gas turbine;
- In 1976, the 1000°C grade M701B gas turbine was developed by digesting and absorbing Westinghouse technology, but it was only factory tested and not officially commercialized;
- In 1984, based on Westinghouse technology, the world's first 1150°C grade M701D heavy-duty gas turbine using a premixed combustor was successfully launched;
- In 1986, independently developed and produced the 1250°C grade MF-111 industrial gas turbine;
- In 1987, M501F was jointly developed with Westinghouse until Westinghouse was acquired by Siemens in 1998; M501F→M701F (F3, F4, F5)→M501G starting from 1993
- In 1988, H25 was commercially launched; in 1991, H15; in 2010, H100;
- From 1997 to 2010, M501G was tested at the experimental power station; in 1999, M701G;
- Since 2004, the Japanese government has funded the research and development of key component technologies for 1700°C ultra-high temperature gas turbines;
- In 2010, M501J began product validation testing and long-term commercial assessment operations;
- In 2015, **M701J** put into operation; →**M501J AC** and **M701 JAC**.

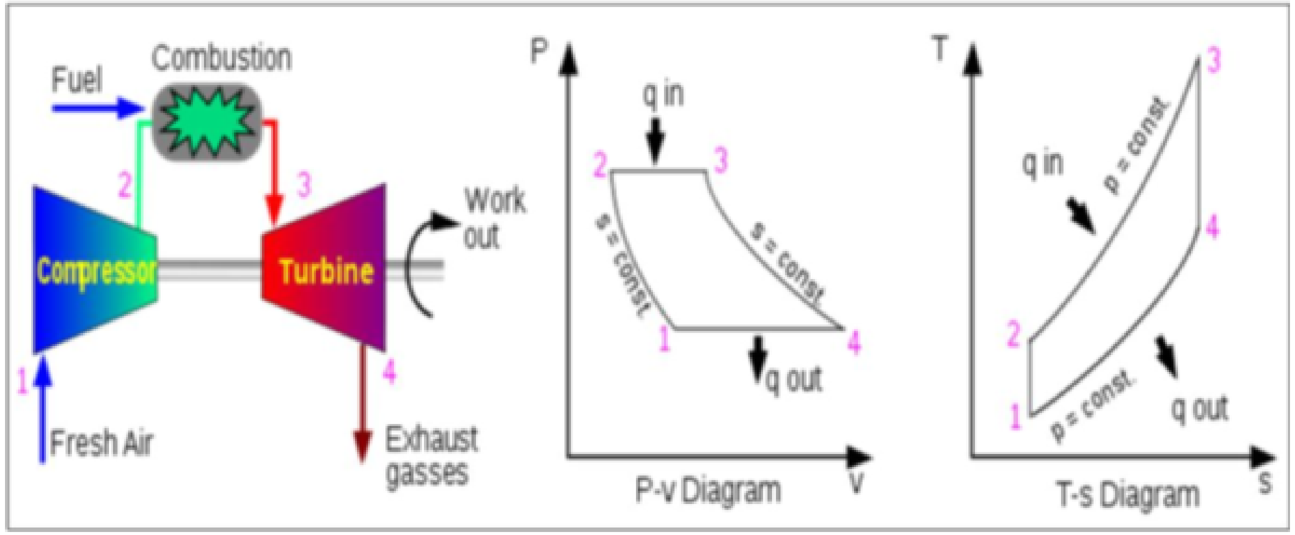
4. Lean premixed combustion in gas turbines– Brayton Cycle

Brayton Cycle

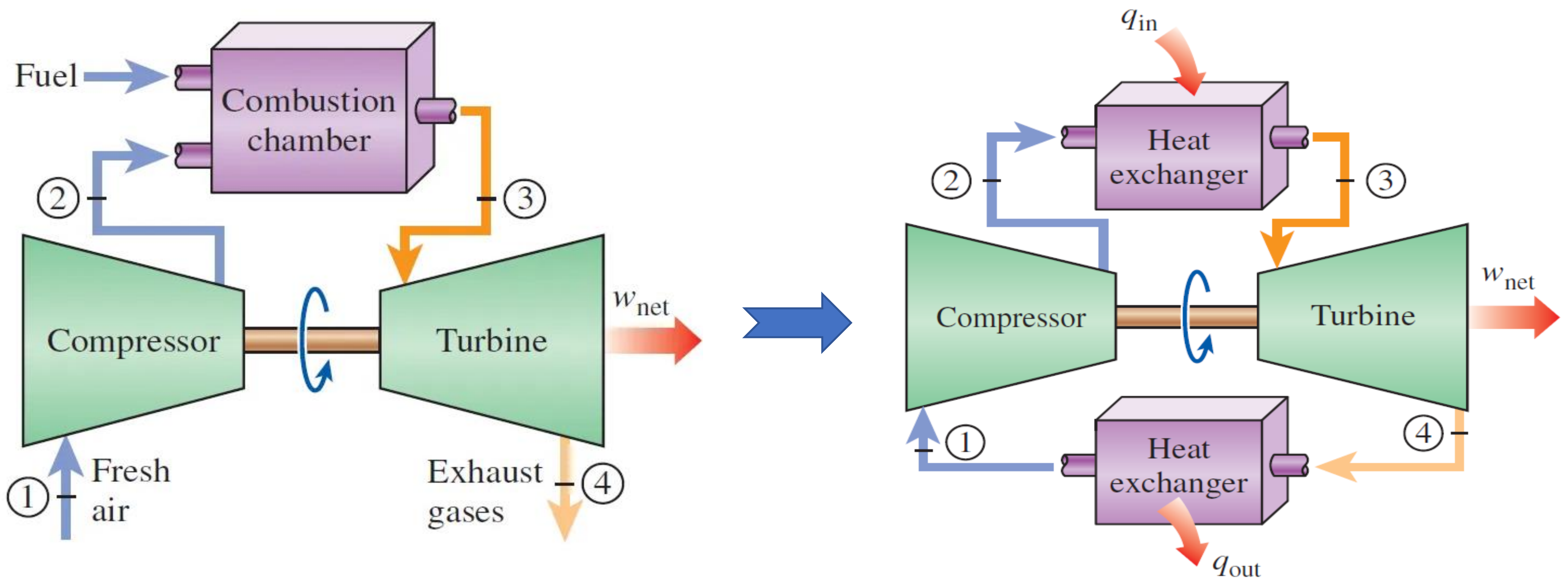
A thermodynamic cycle that describes the workings of the gas turbine engine

1-2 Isentropic compression 2-3 Isobaric heat addition

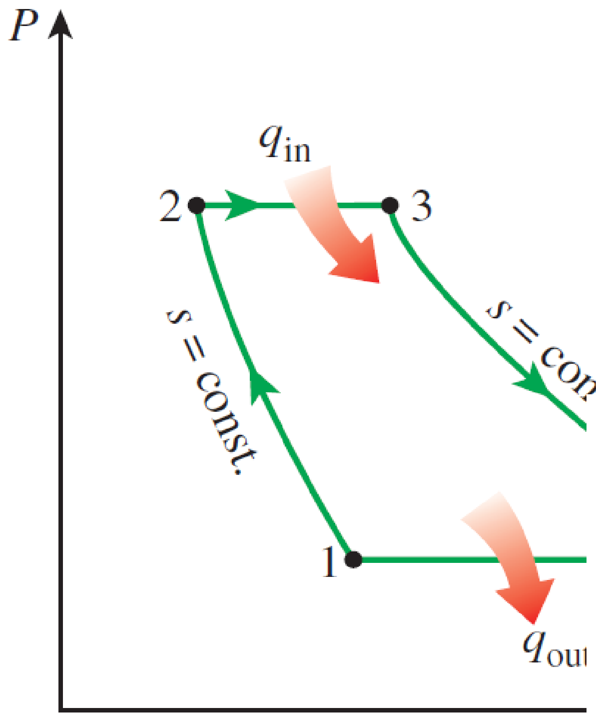
3-4 Isentropic expansion 4-1 Isobaric heat rejection



4. Lean premixed combustion in gas turbines– Brayton Cycle



4. Lean premixed combustion in gas turbines– Brayton Cycle

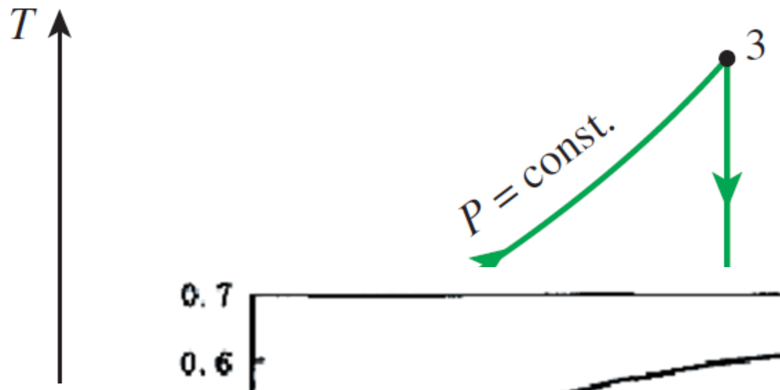


(b) P-v diagram

$$T_2 = T_1 * \left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}}$$

$$T_3 = T_4 * \left(\frac{p_3}{p_4}\right)^{\frac{k-1}{k}}$$

k: adiabatic index



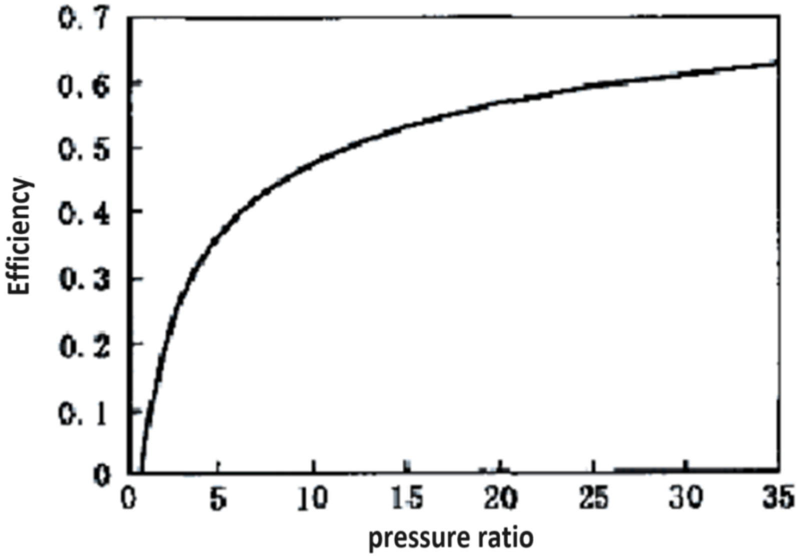
$$\eta_{th,Brayton} = \frac{w_{out}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{c_p(T_4 - T_1)}{c_p(T_3 - T_2)} = 1 -$$

Since process 1-2 and process 3-4 are both isentropic:

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = \left(\frac{P_3}{P_4}\right)^{\frac{k-1}{k}} = \frac{T_3}{T_4}$$

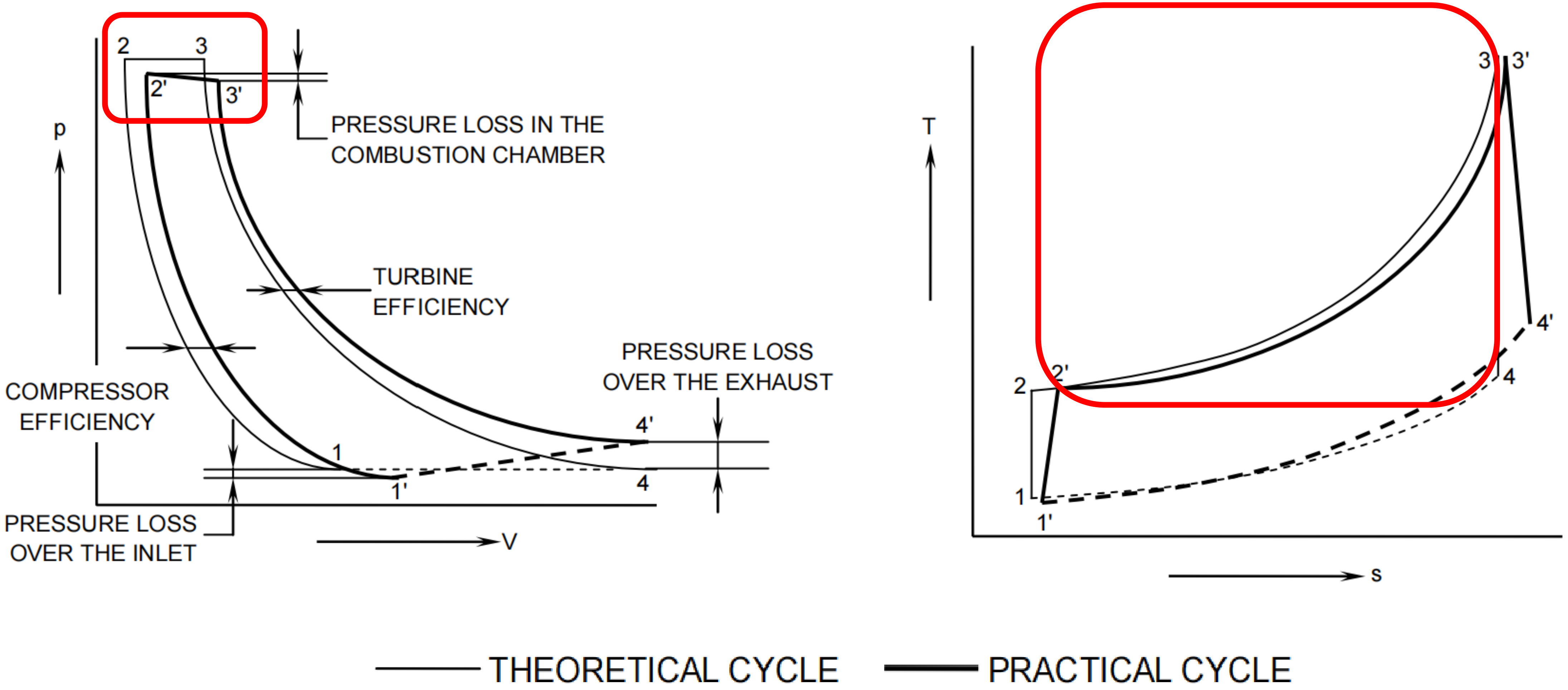
So, its efficiency:

$$\eta_{th,Brayton} = 1 - \frac{1}{r_p^{\frac{k-1}{k}}}$$ **Where** $r_p = \frac{P_2}{P_1}$ **is pressure ratio ,** $k = \frac{c_p}{c_v}$



Efficiency- pressure ratio curve of ideal simple cycle

4. Lean premixed combustion in gas turbines– Brayton Cycle

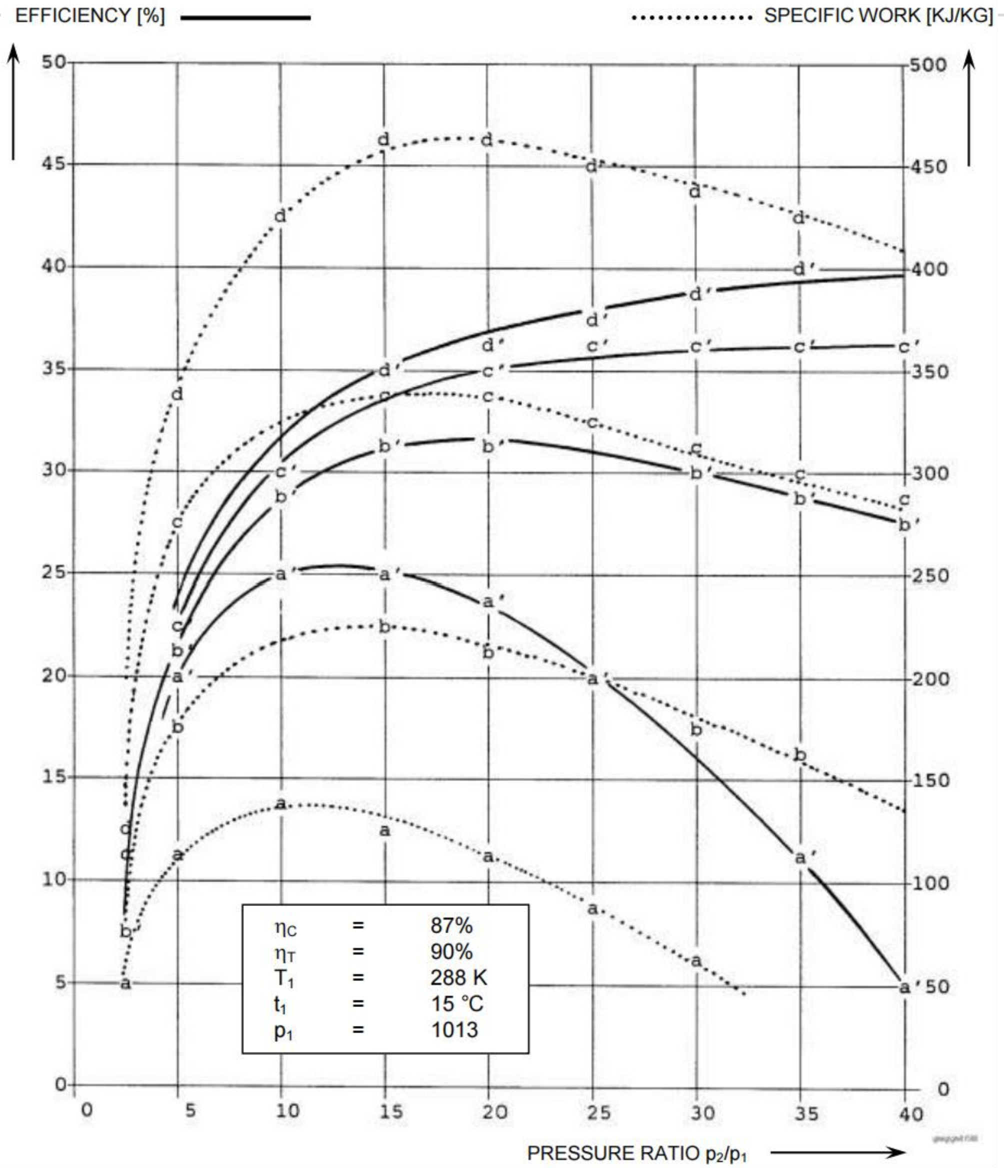


4. Lean premixed combustion in gas turbines– Brayton Cycle

Relevant factors to the real efficiency:

- **P2/P1**
- **T3/T1**

Note:
The pressure ratio at max. efficiency is different from the pressure ratio at max. specific work



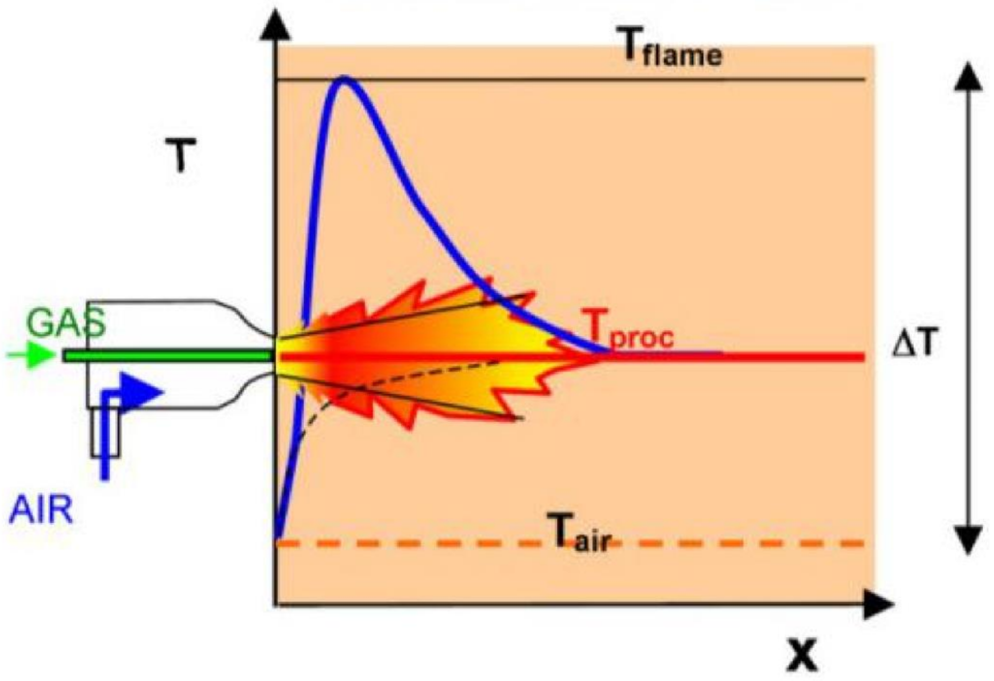
a & a': T_3 = 1000 K = 727 °C
b & b': T_3 = 1200 K = 927 °C
c & c': T_3 = 1400 K = 1127 °C
d & d': T_3 = 1600 K = 1327 °C

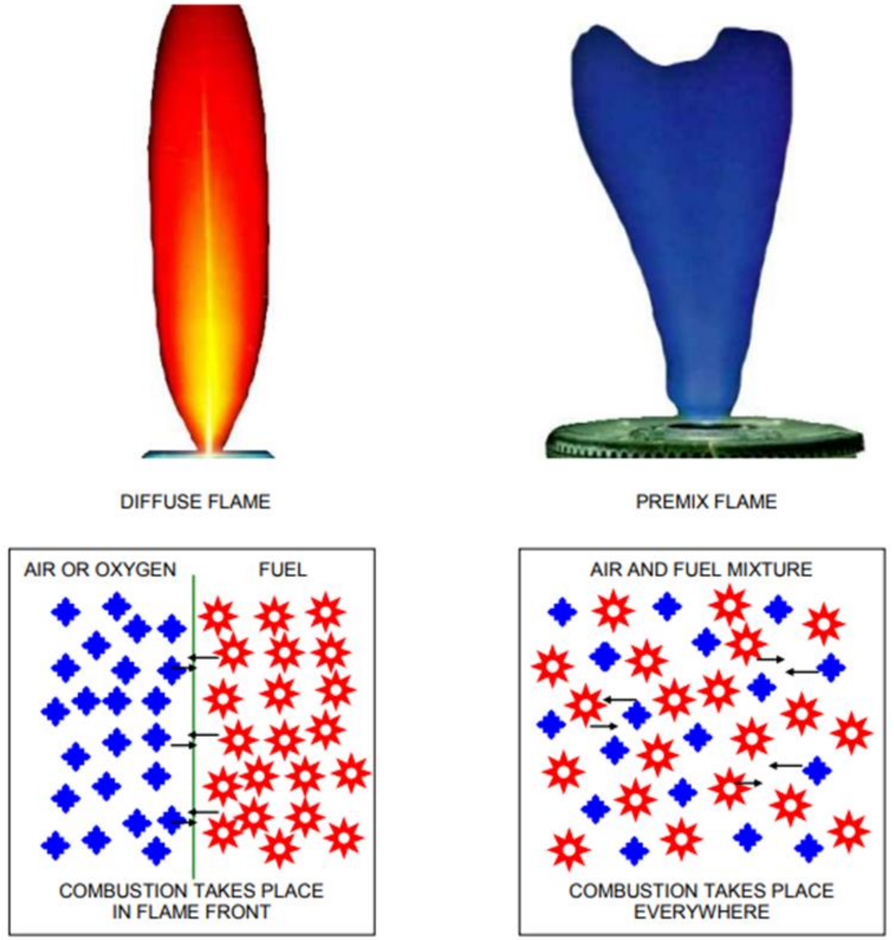
- **Material's tolerance to high temperature, etc:**
  - Cooling
  - Hot gas path parts' maintenance, etc.
- **Emissions**

4. Lean premixed combustion in gas turbines– T3

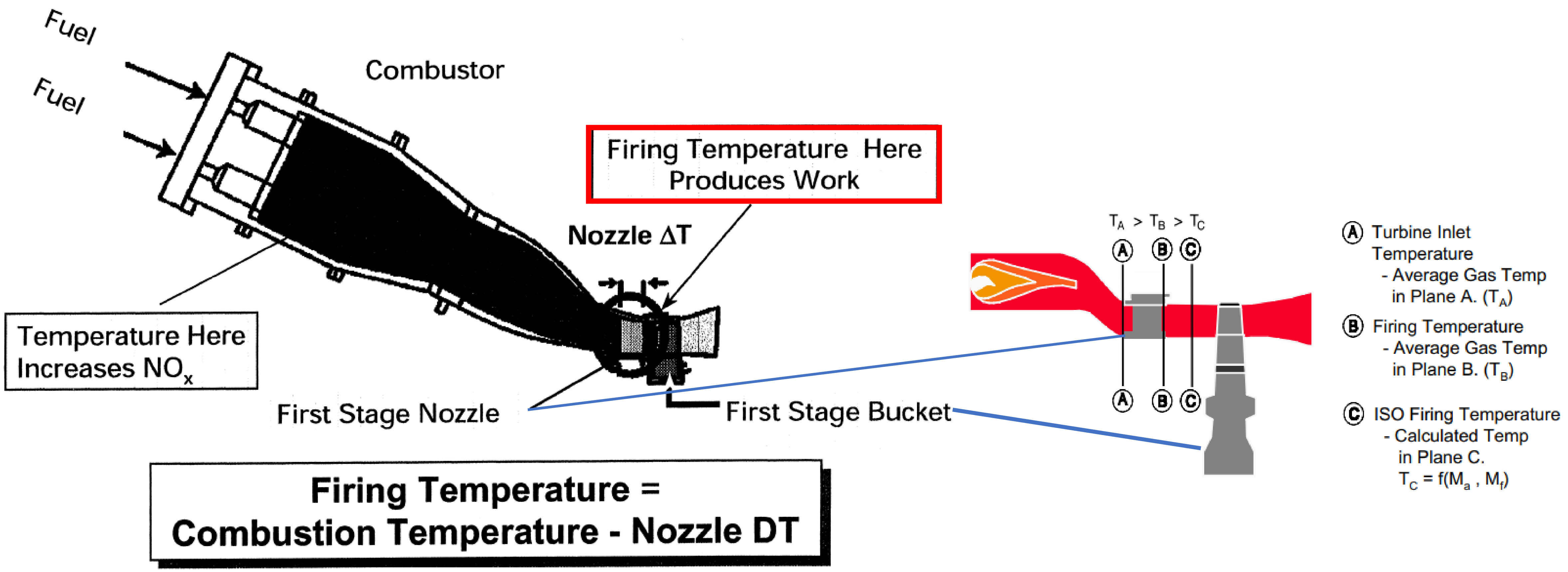
How do we reduce T for low emissions (thermal NOx), while the efficiency is still kept high (T3)?

- Peak T vs. avg T
- Diffusion vs. premixed

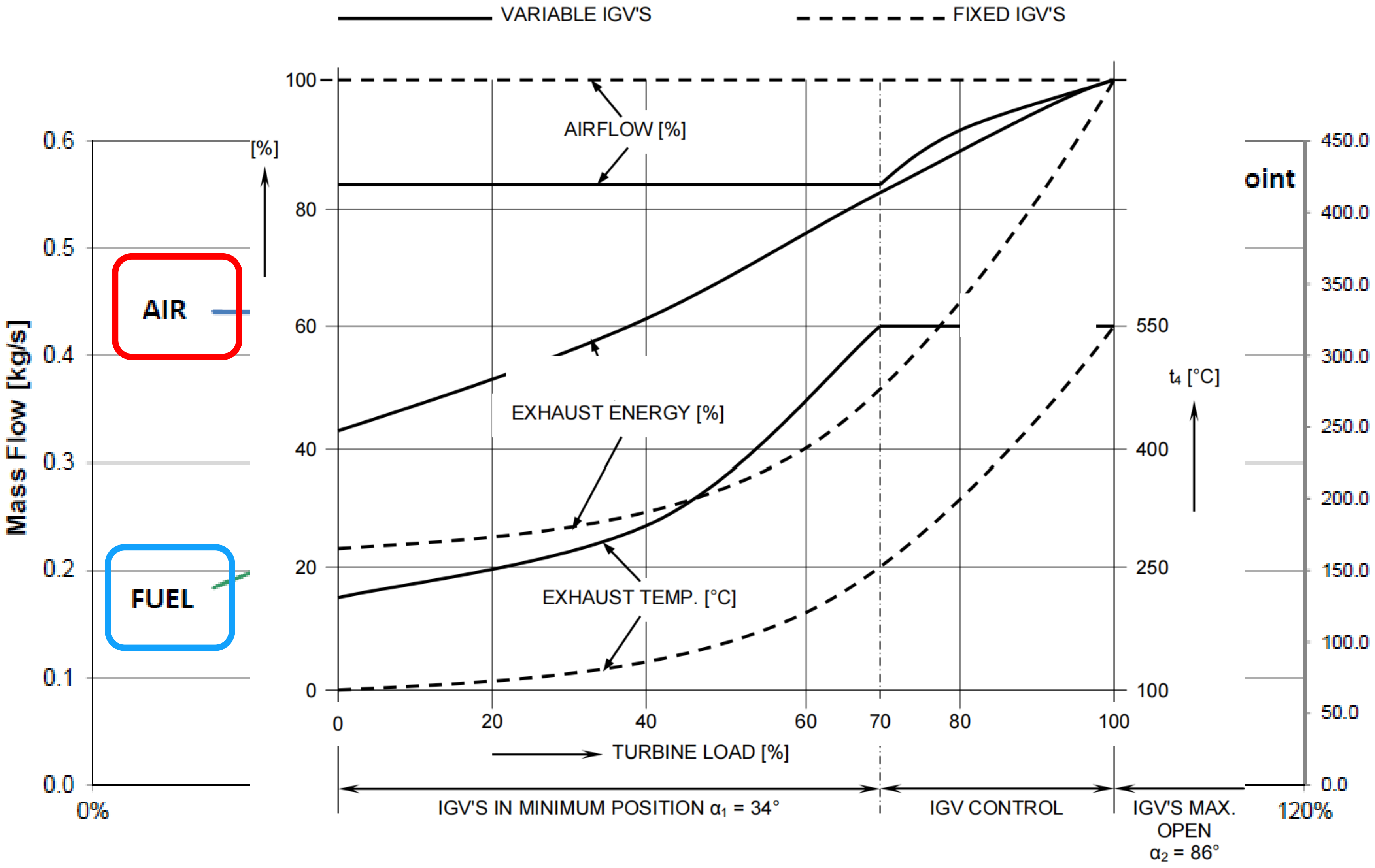




4. Lean premixed combustion in gas turbines– firing T



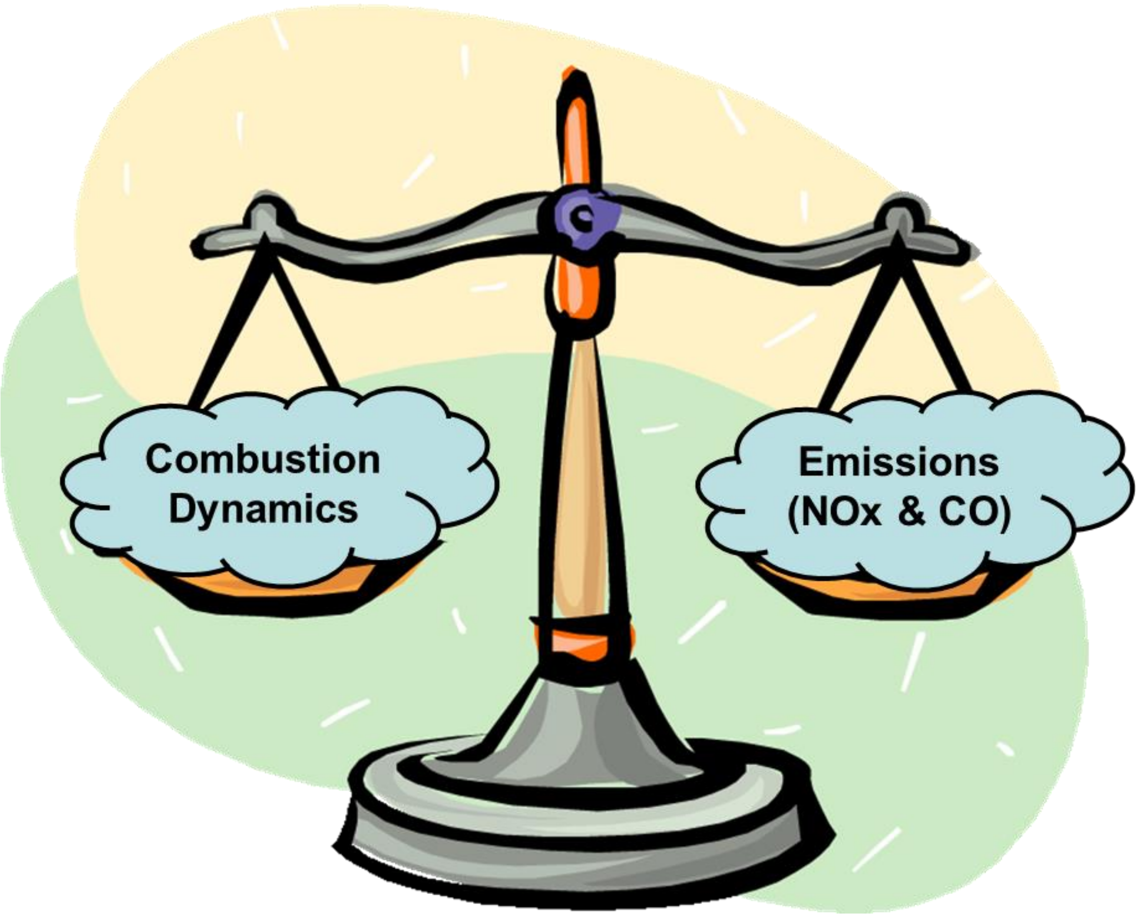
4. Lean premixed combustion in gas turbines– IGV’s



influence of the variable inlet guide vanes (IGV's)

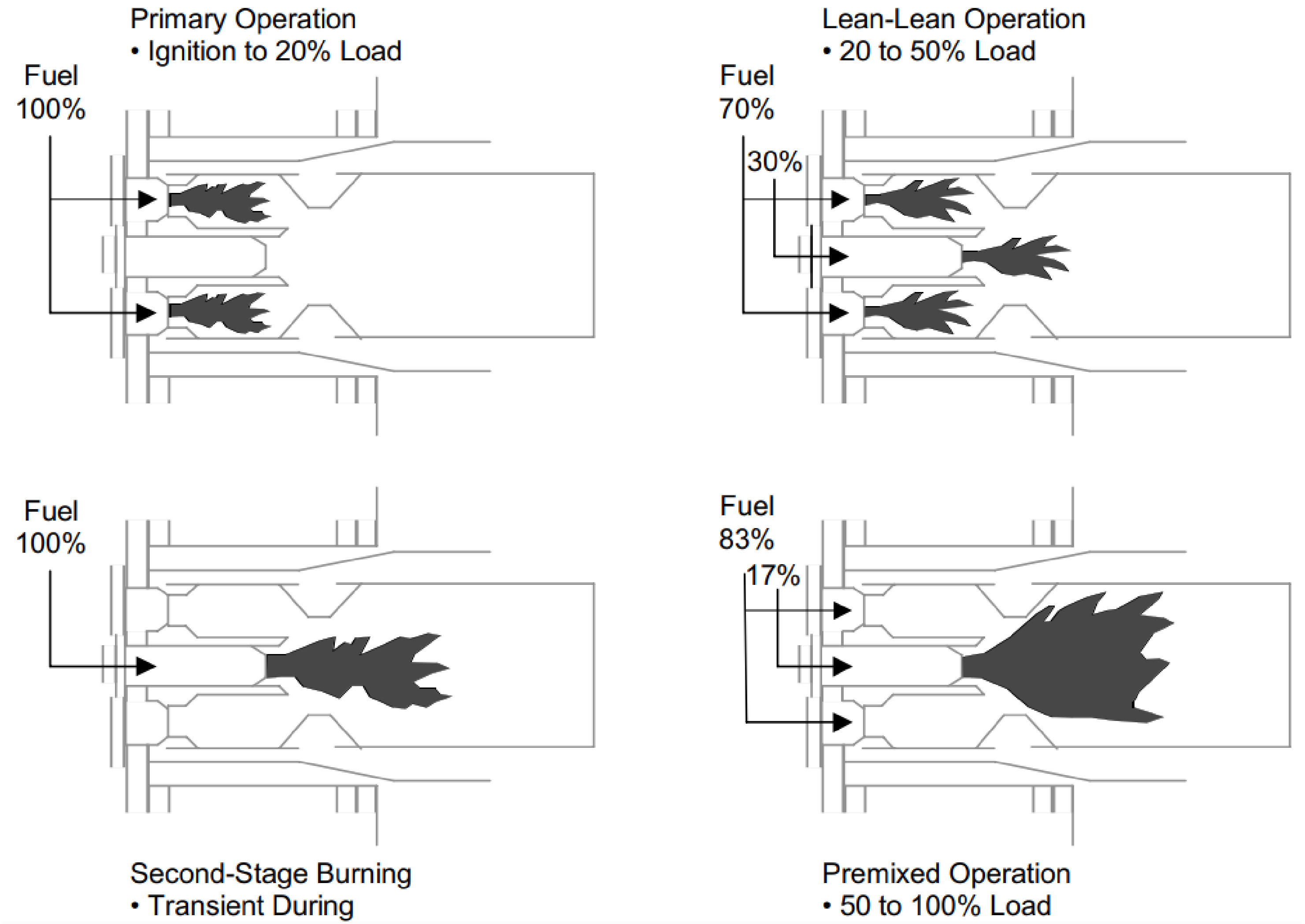
4. Lean premixed combustion in gas turbines– considerations for tuning

- **Main Operating Constraints:**
  - Emissions NOx & CO
  - Combustion Dynamics
- **Other Considerations:**
  - Lean Blow-out
  - Flashback
  - Auto-ignition
  - Turn-down



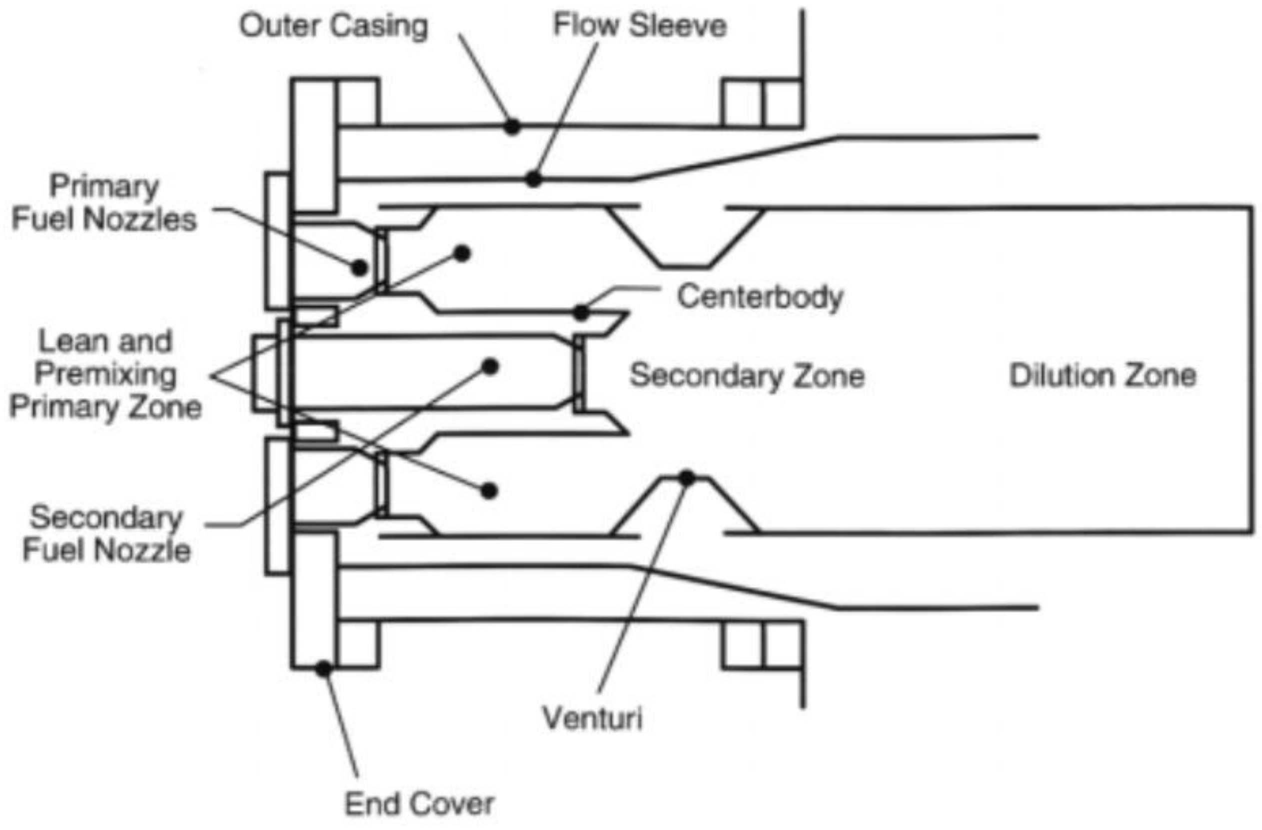
Weather; Fuel components; Operating conditions; Hardware degradation; etc.

4. Lean premixed combustion in gas turbines– DLN1 combustion modes



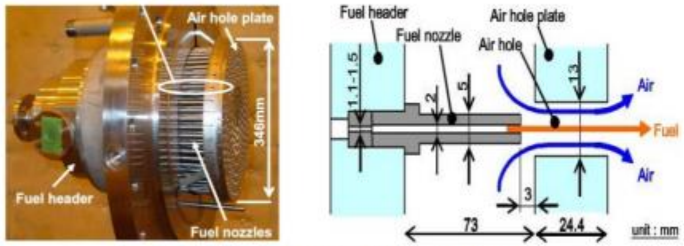
(L.B. Davis, S.H. Black, Dry Low NOx Combustion Systems for GE Heavy-Duty Gas Turbines, 2010, Schenectady, NY)

4. Lean premixed combustion in gas turbines– DLN1 parts



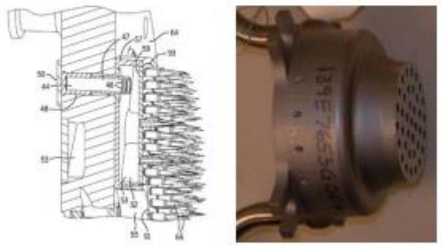
Lean combustion → Combustion instability → Thermoacoustics → Combustion tuning (mixing condition)

4. Lean premixed combustion in gas turbines– DLN combustor evolution

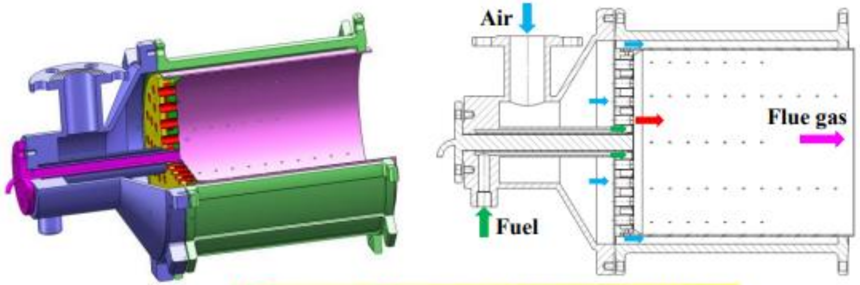


三菱—日立公司 微混燃烧器 [1]

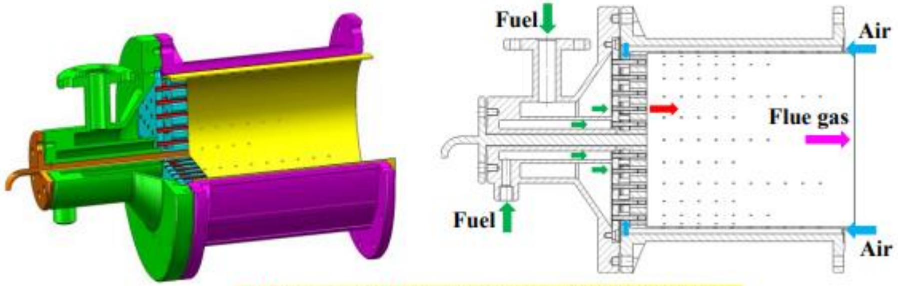
UCI & Parker
公司微混燃烧器[2]



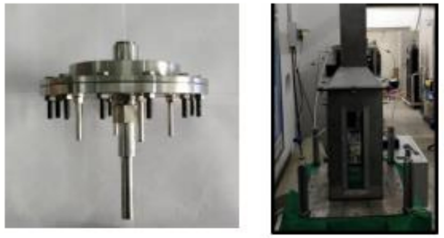
GE公司 微混燃烧器 [3]



顺流分布式外交叉射流微混燃气轮机燃烧室 [4]

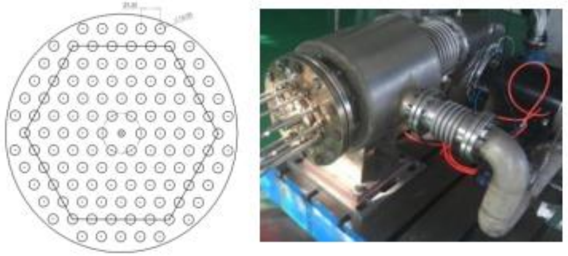


逆流分布式内交叉射流微混燃气轮机燃烧室 [5]



Single

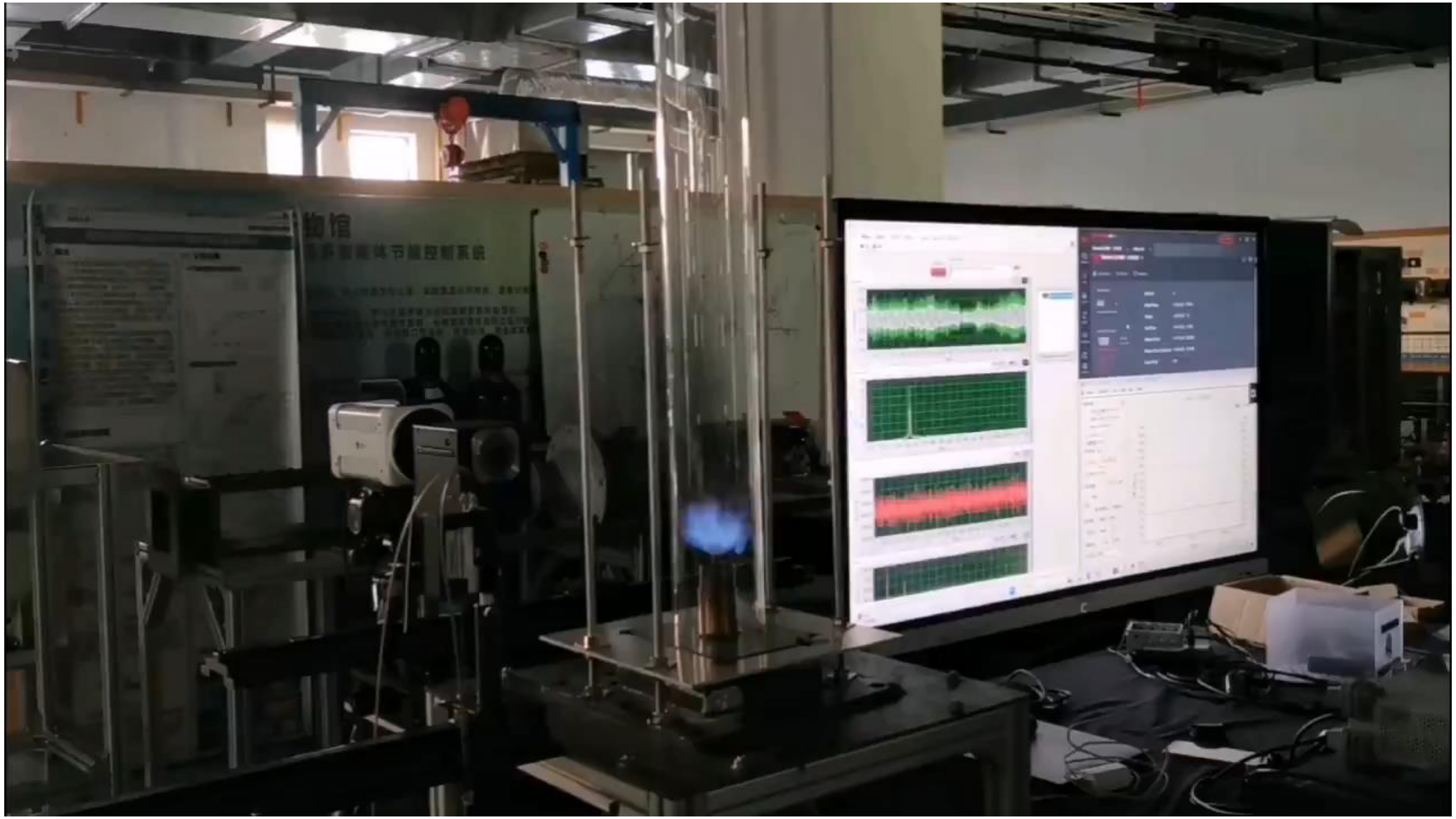
Multiple



Unit

([1] Asai T, GT2011-45295; [2] Steven R Hernandez, GT2008-50854; [3] William D York, GT2012-69913; [4] Penghua Qiu, J Energy Inst 103 (2022) 72-83; [5] Penghua Qiu, J Energy Inst 102 (2022) 100-117)

4. Lean premixed combustion in gas turbines– Thermoacoustic



(Deng Pan, Chenzhen Ji, Tong Zhu et al., Thermoacoustic phenomena test rig (**non-premixed** combustion), Tongji University, 2023)

5. Another topic of importance (reflection): communication

What is the fact?

Most of the time, we **assume** that other people **should** understand us without telling them our perspective.

High-context vs. low-context cultures

	Low-Context	High-Context
Example Countries	US, UK, Canada, Germany, Denmark, Norway	Japan, China, Egypt, Saudi Arabia, France, Italy, Spain
Business Outlook	Competitive	Cooperative
Work Ethic	Task-oriented	Relationship-oriented
Work Style	Individualistic	Team-oriented
Employee Desires	Individual achievement	Team achievement
Relationships	Many, looser, short-term	Fewer, tighter, long-term
Decision Process	Logical, linear, rule-oriented	Intuitive, relational
Communication	Verbal over Non-verbal	Non-verbal over Verbal
Planning Horizons	More explicit, written, formal	More implicit, oral, informal
Sense of Time	Present/Future-oriented	Deep respect for the past
View of Change	Change over tradition	Tradition over change
Knowledge	Explicit, conscious	Implicit, not fully conscious
Learning	Knowledge is transferable (above the waterline)	Knowledge is situational (below the waterline)

5. Reflection– communication

Science of 'the Dress': Why We Confuse White & Gold with Blue & Black

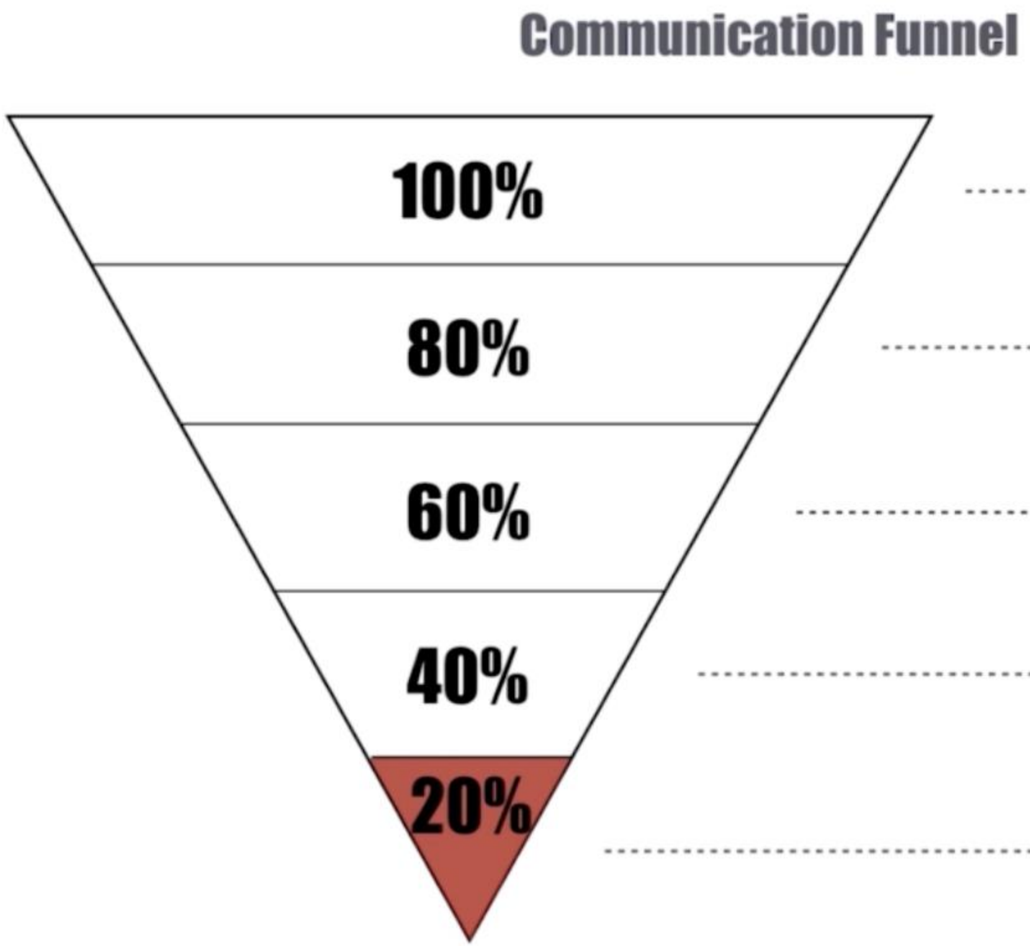
We are “designed” different!

5. Reflection– communication

Counter intuitive ways to take on another person's point of view

(https://www.reddit.com/r/im14andthisisdeep/comments/evhikm/boat_vs_land/?rdt=52766)

5. Reflection– communication

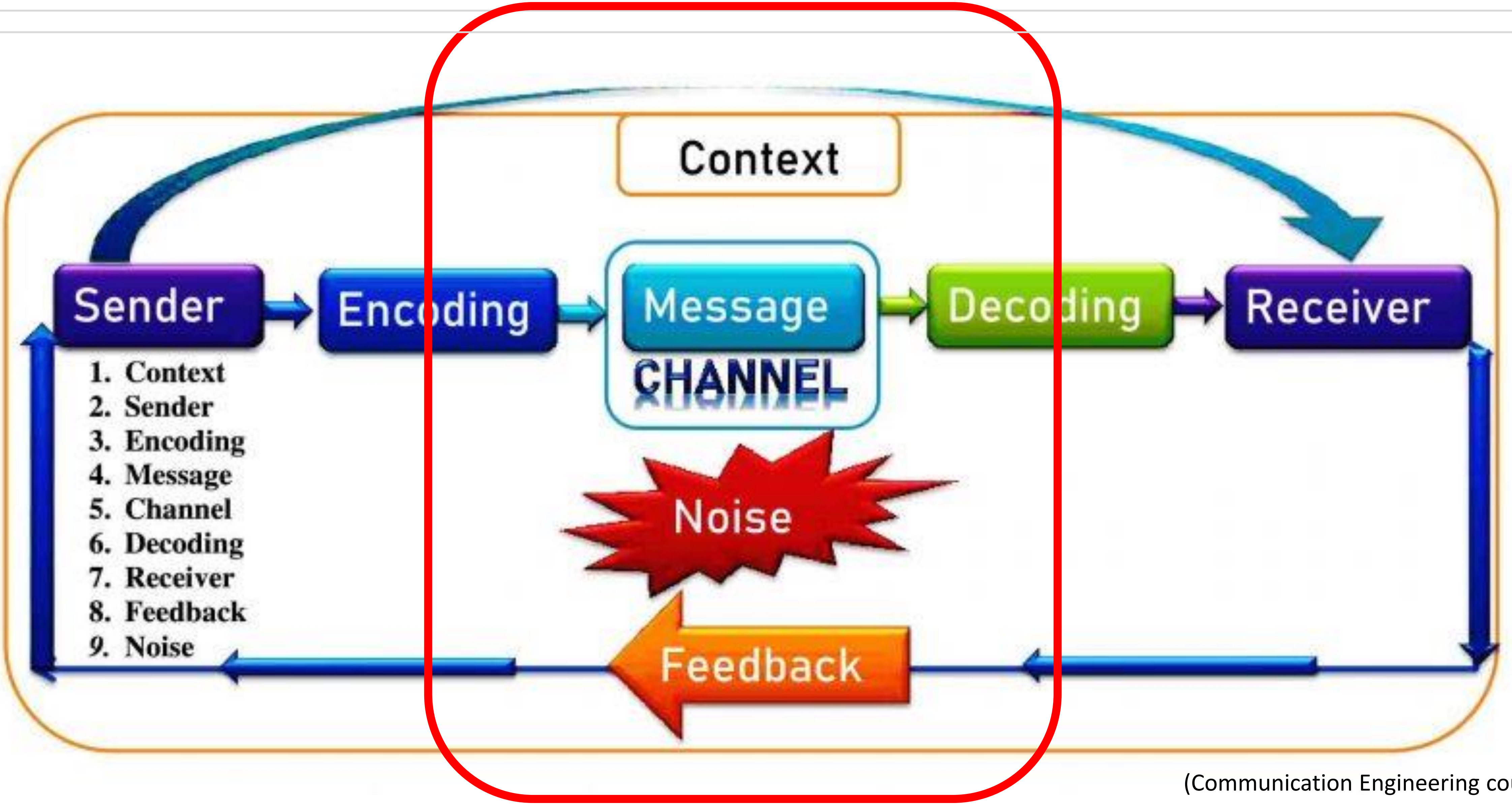


- What you want to tell
- What you express
- What the other one hears
- What the other one understands
- What the other one does

(Qifeng, 2019. McKinsey Business Communication and Text Writing. China: Tianjin Science Technology Publishing House)

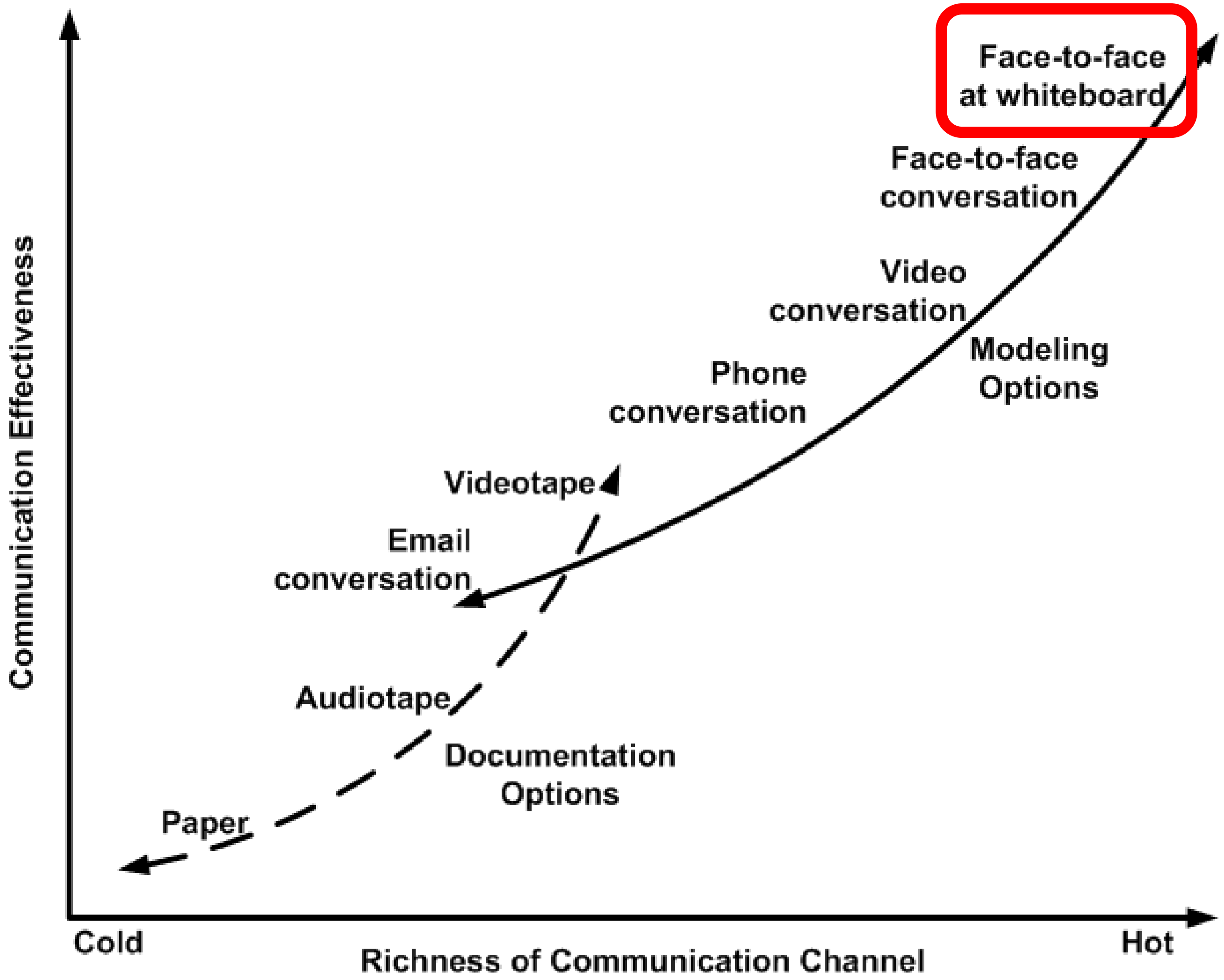
5. Reflection– communication

5. Reflection– communication



(Communication Engineering course)

5. Reflection– communication



Bear in mind:

- Communication is always a two-way process
- It is the process of sharing information back and forth between (two) parties

(Personal Leadership Course, RSM, 2018)

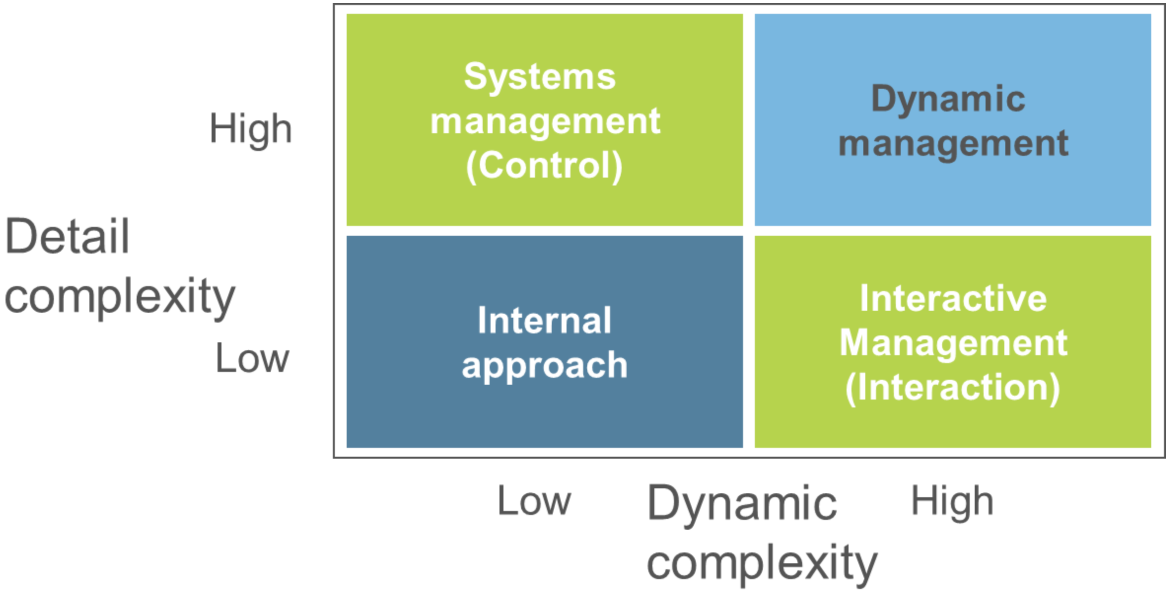
5. Reflection– technical, organizational and external complexity analysis

T Technical Complexity (17 elements)	O Organizational Complexity (17 elements)	E External complexity (13 elements)
High number of project goals	**High project schedule drive**	Level of competition
Non–alignment of project goals	**Lack of Resource & Skills availability**	Instability of project environment
Unclarity of project goals	Lack of Experience with parties involved	Company internal strategic pressure
Uncertainties in scope	Lack of HSSE awareness	**Lack of experience in the country**
Strict quality requirements	Interfaces between different disciplines	Remoteness of location
Project duration	Number of financial sources	**Interference with existing site**
Size in CAPEX	Number of contracts	Required local content
Number of locations	Type of contract	**Lack of company internal support**
Newness of technology (world–wide)	Number of different nationalities	Political influence
Lack of experience with technology	Number of different languages	Dependencies on external stakeholders
High number of tasks	Presence of JV partner	**Variety of external stakeholders' perspectives**
High variety of tasks	Involvement of different time zones	Number of external stakeholders
Dependencies between tasks	Size of project team	External risks
Uncertainty in methods	Incompatibility different pm methods / tools	
Involvement different technical disciplines	**Lack of trust in project team**	
Conflicting norms and standards	Lack of trust in contractor	
Technical risks	Organizational risks	

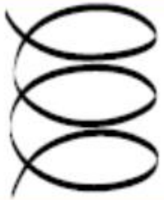
(Project management: mastering complexity, TUDleft online course)

5. Reflection– dynamic management

Waterfall vs. Agile?

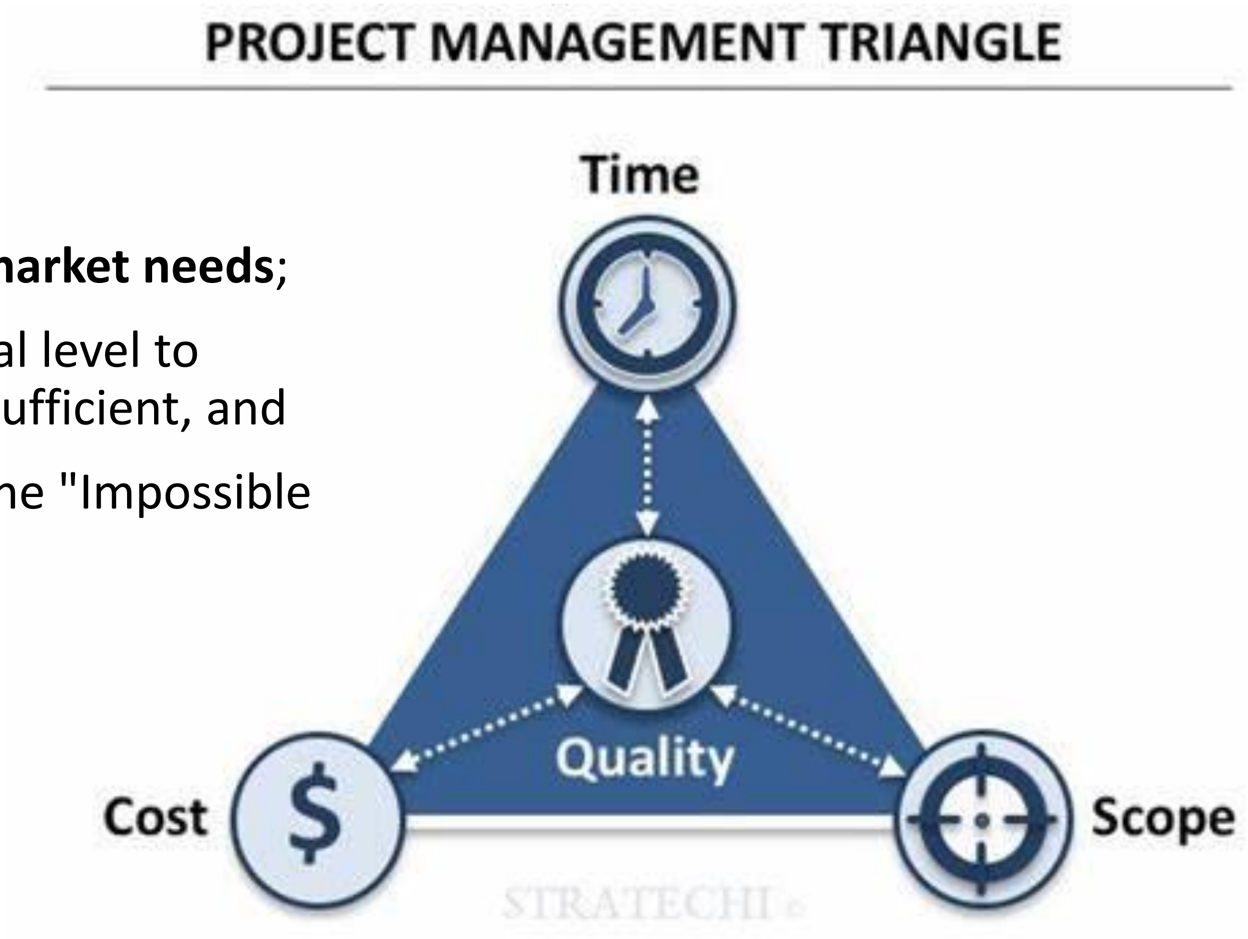


(Project management: mastering complexity, TUDleft online course)

Strategy	Control	Interaction
Illustration		
		
Basis		
Fit for	Detail complexity	Dynamic complexity
Problems are	Unambiguous, fixed and independent of stakeholders	Ambiguous, changing, determined by stakeholders
Problem solving	Linear	Iterative
Theoretical basis	Organisational design Systems management	Interactive management Complexity management
Management strategies		
	1 Break down in terms of • in time • in end product • organisation	1 Alignment 2 Redefinition of the problem and change of scope
	2 Management processes • schedule • costs • quality • risks	3 Using short term predictability • systematic evaluation • selection of successful strategies
		4 Variation • in strategies • scenario building & pattern analysis

5. Reflection– project management

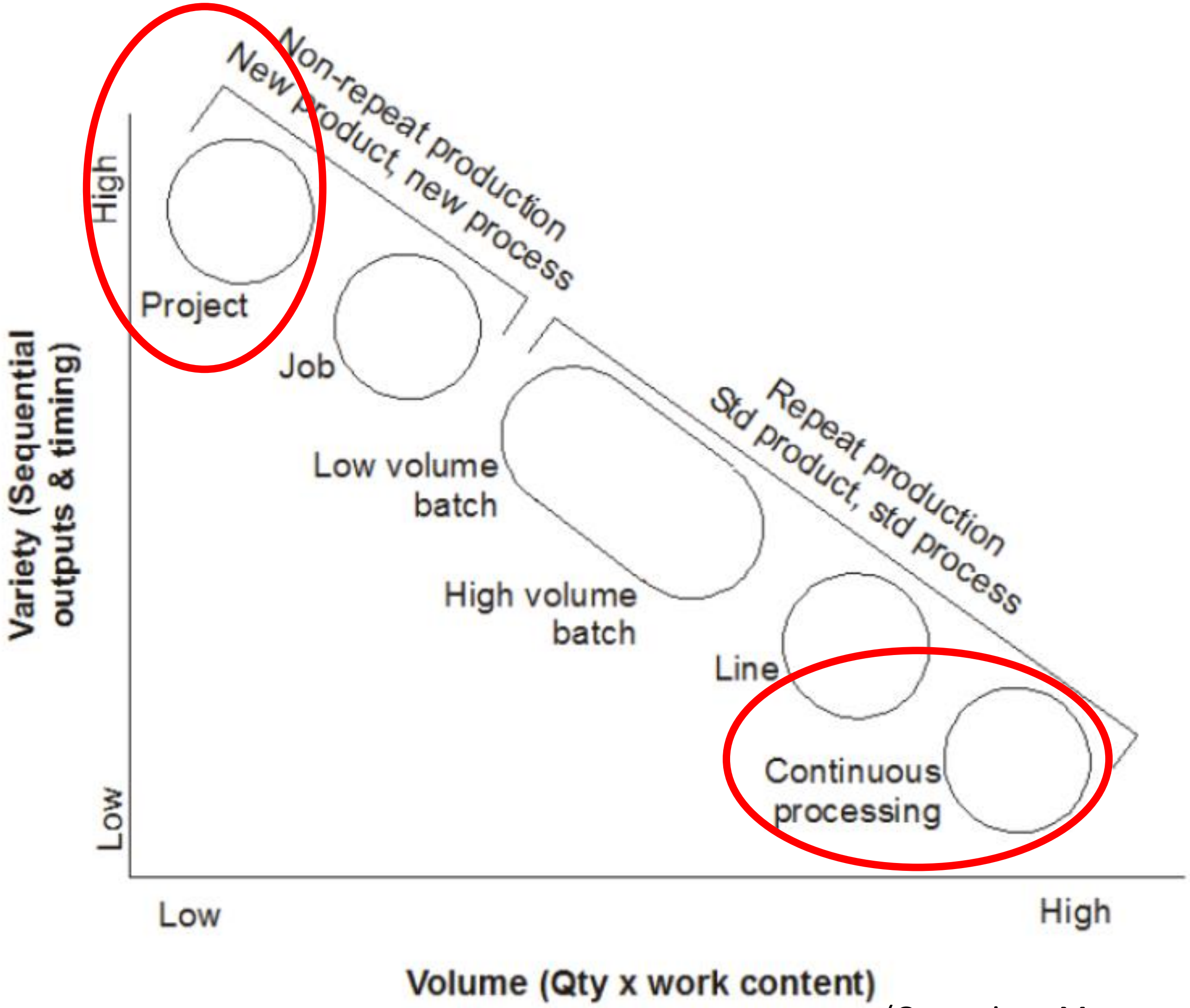
- Classify target customer groups according to **market needs**;
- Declare strategic priorities at the organizational level to make the right choices when resources are insufficient, and
- Concentrate on solving important problems (the "Impossible Triangle" of project management)



(https://www.stratechi.com/project-management-triangle/)

5. Reflection– projects vs. operations

- The connection and difference between **operations and projects/R&D**, and the setting of related processes



(Operations Management course, RSM, 2019)

5. Reflection– supply chain, financial impact and talent strategy

Develop and cultivate long-term and stable **supply chain** partners (quality control and other uncertain factors ("bullwhip effect");

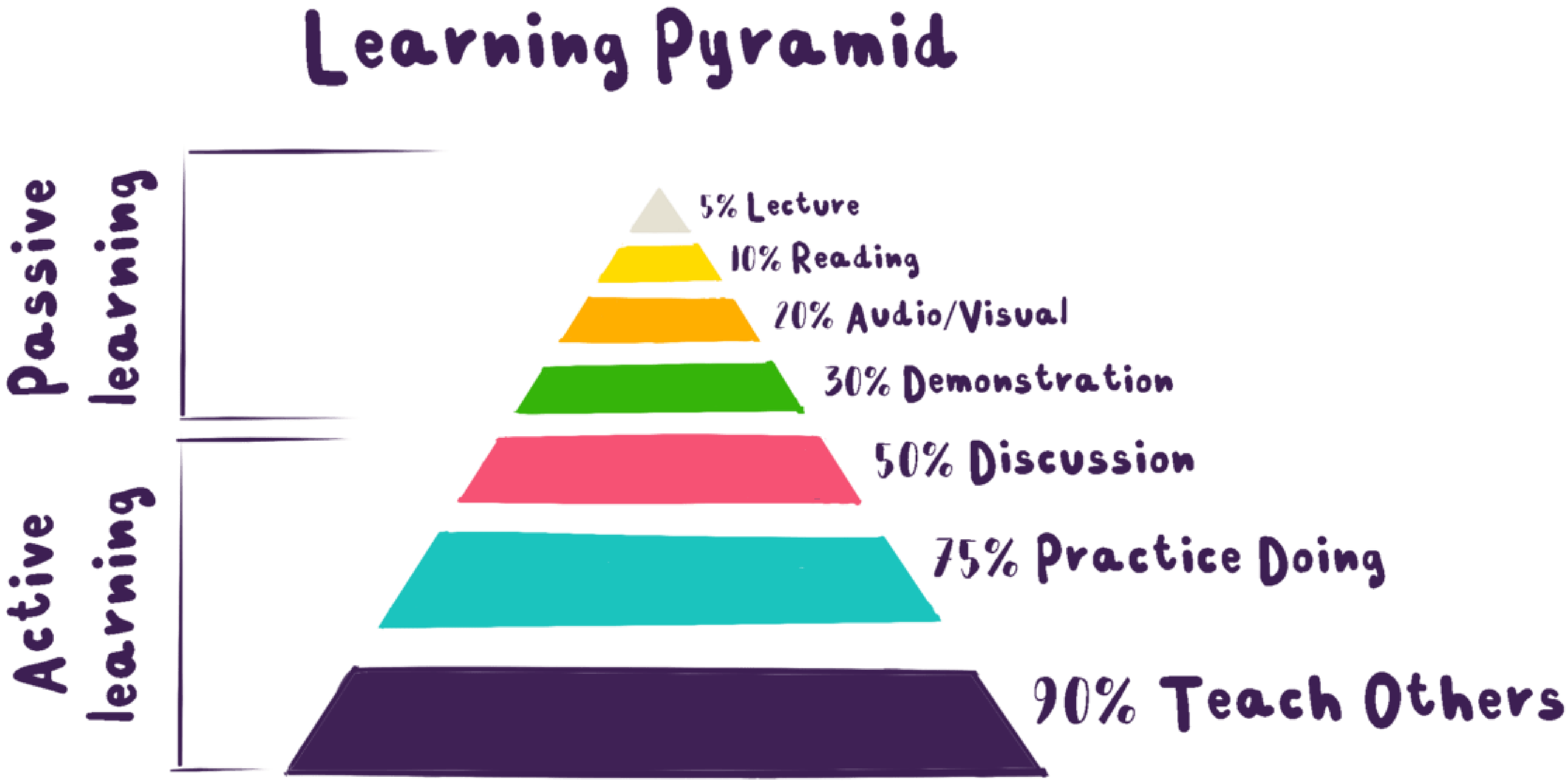
Timely assess the **financial impact** of the project on the organization from the perspective of profit and loss, assets and liabilities and cash flow;

Talent cultivation, especially compound talents, to cope with the uncertainty of the changing market and interface/communication problems commonly encountered in collaboration between different technical types of work, etc.

5. Reflection– team dynamics (keep in mind when you lead a team)

(Tuckman's stages of group development)

5. Reflection– learning



(https://www.plushnuggets.com/blog/2020/12/18/forms-learning-pyramid/)

5. Reflection– growth mindset vs. fixed mindset

(Ameet Ranadive, Fixed v. Growth Mindset, https://medium.com/leadership-motivation-and-impact/fixed-v-growth-mindset-902e7d0081b3)

Questions? Thanks for your attention!

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