Novel Combustion Cycle Involving Oxygen and Water

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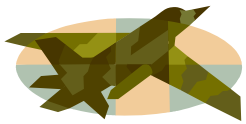
Azmi Osman
Principal Engineer
PETRONAS Research S.B.

Source of the problem to world's energy and emission problems



Emissions

Fuel

X kJ

Heat engine

Carbon dioxide

Waste heat

2/3 X kJ

Useful work

1/3 X kJ

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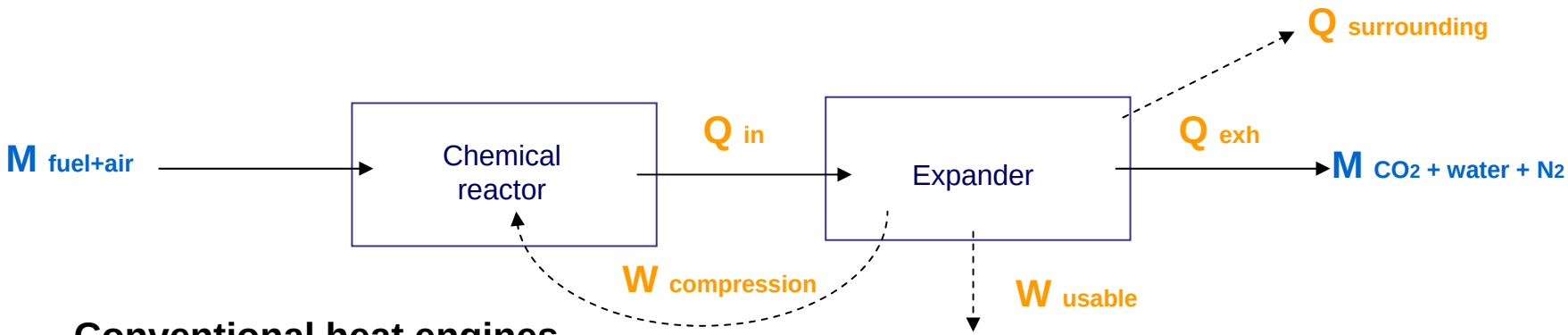
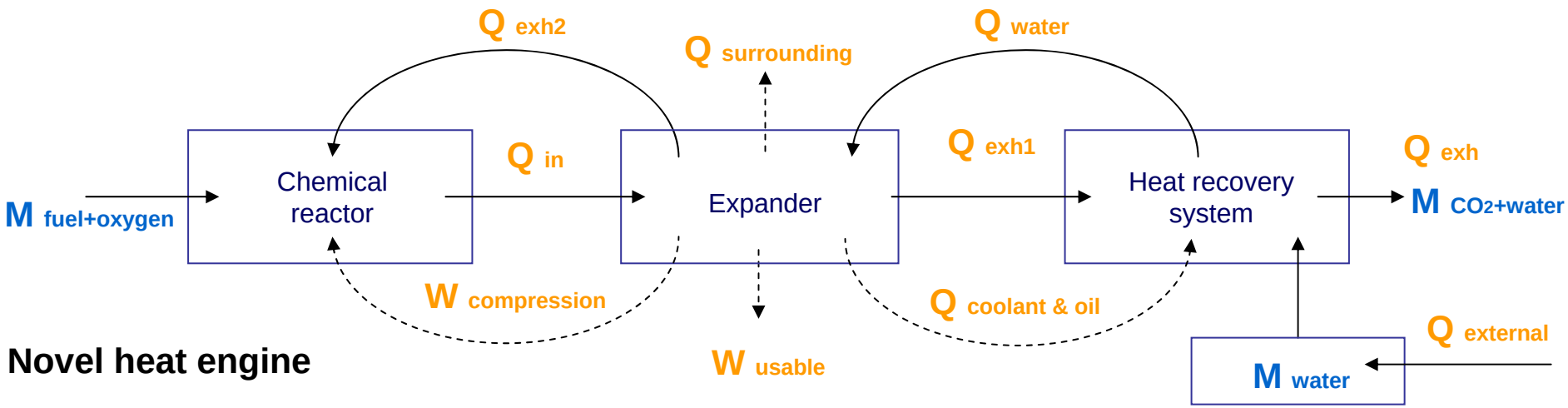
Revolutionizing the combustion engine at its most fundamental form



Conventional heat engines



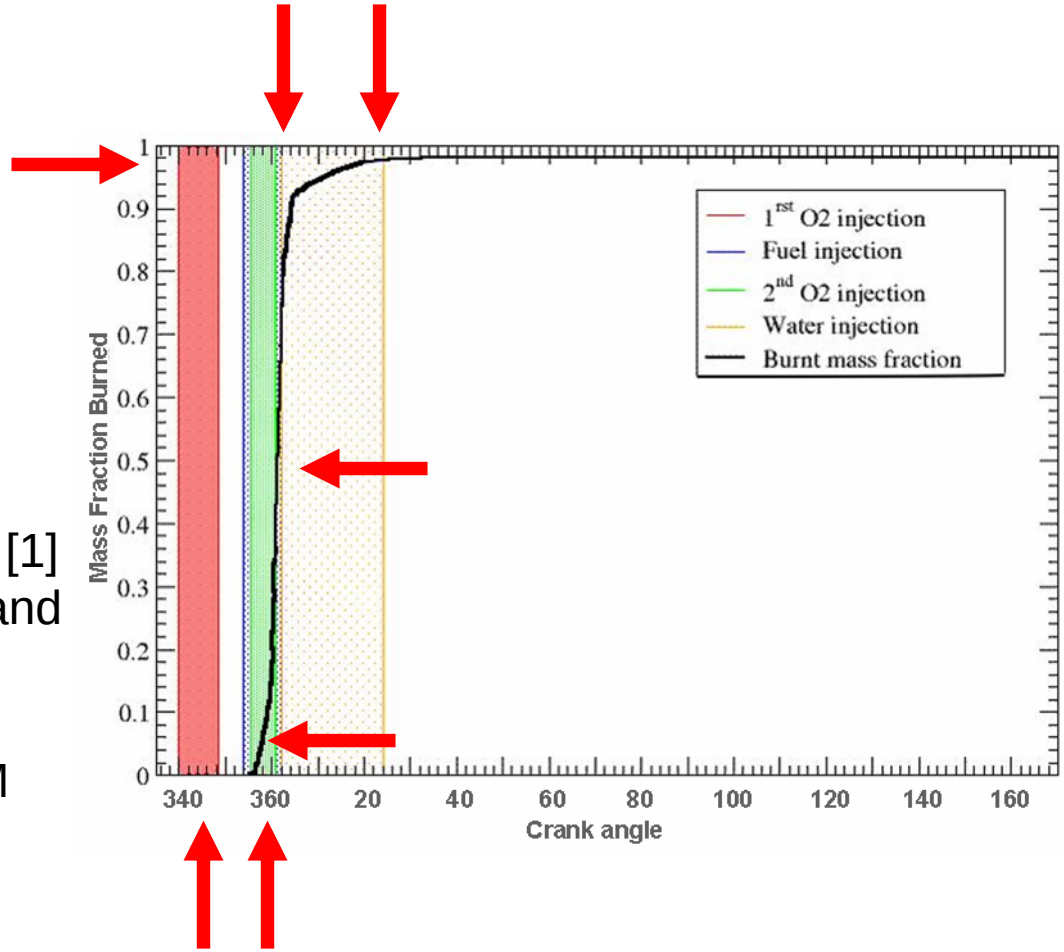
Novel heat engine

Step 1; Maximize combustion heat absorption
Step 2; Recover the remaining heat
Step 3; Reuse the recovered heat

Replacement of air with high purity oxygen

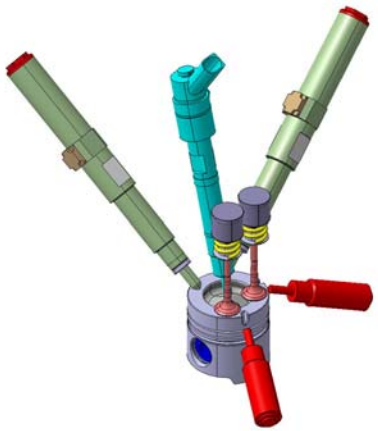
Why oxygen instead of air?

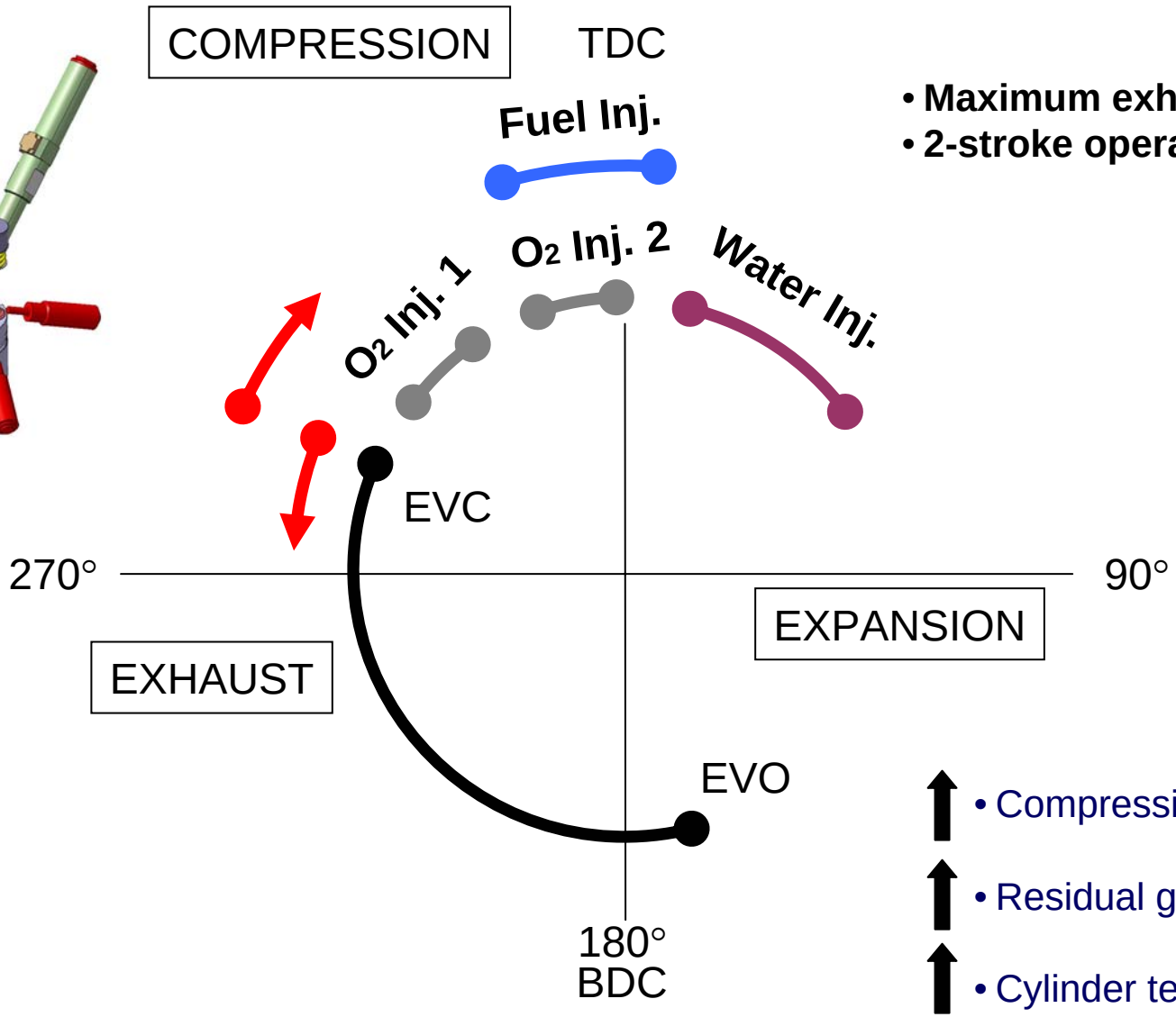
- Reduce charge by at least 78%
- Enables gas injector to be used
- Shorten ignition delay
- Accelerates heat release
- Water can be injected early
- Flame quenching is minimized
- Cheap to produce 0.3 kWhr/Nm^3 [1]
- Allows broader range of gaseous and liquid fuels
- Maximizes fuel oxidation
- Drastically reduce CO, HC and PM emissions
- Lack of nitrogen generates almost non-existence NO x



1. Capogrosso, L., Zinno, G., Gasser-Coze, H., “Optimized Steel Production with Oxygen for Blast Furnaces at ILVA, Taranto Works, Italy”, http://publication.airliquide.com/business/industry/metals/Oxygen_injection_smelting_furnaces.pdf

Exhaust valve timing and lift at full power

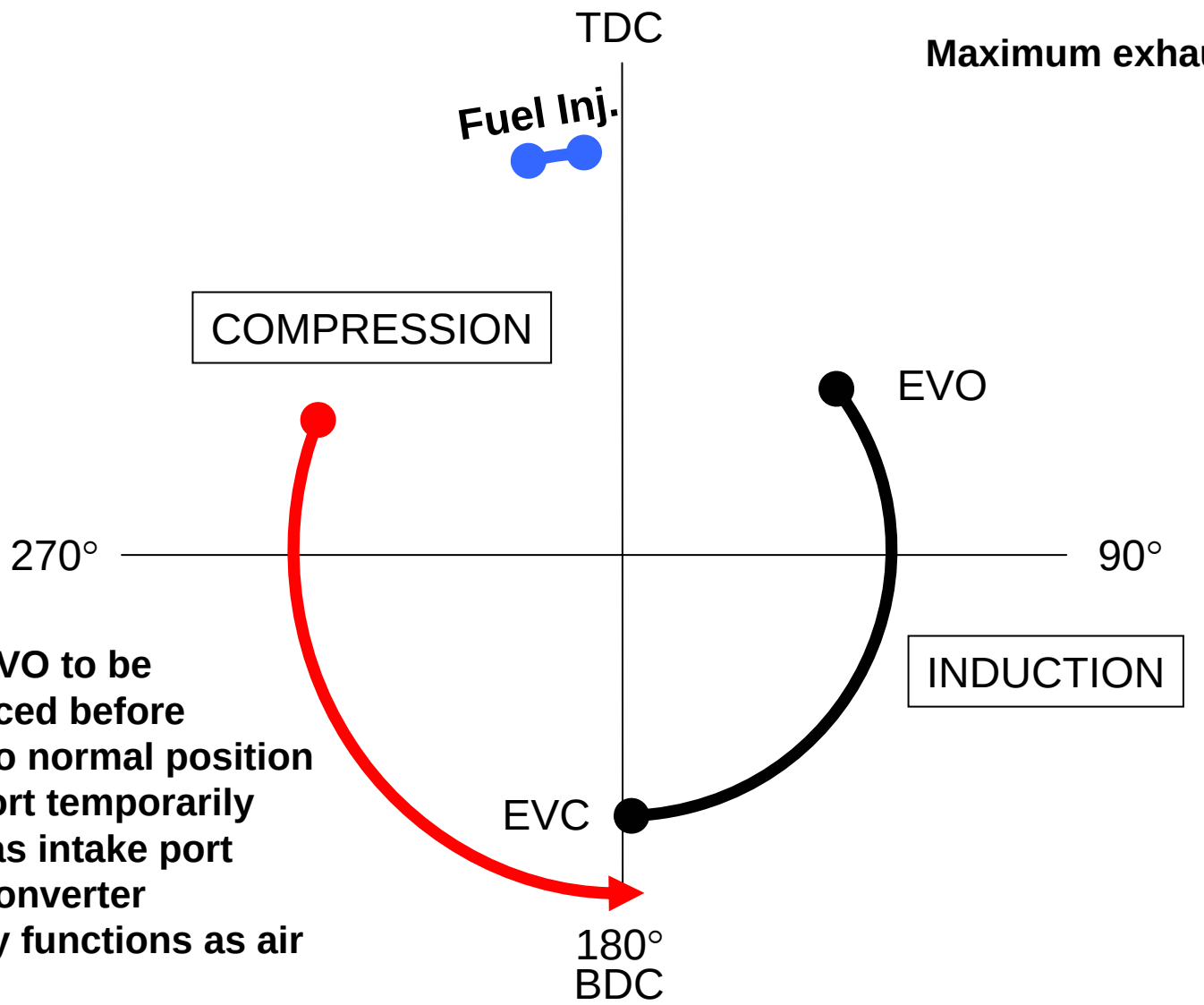




- **Maximum exhaust valve lift**
- **2-stroke operation**

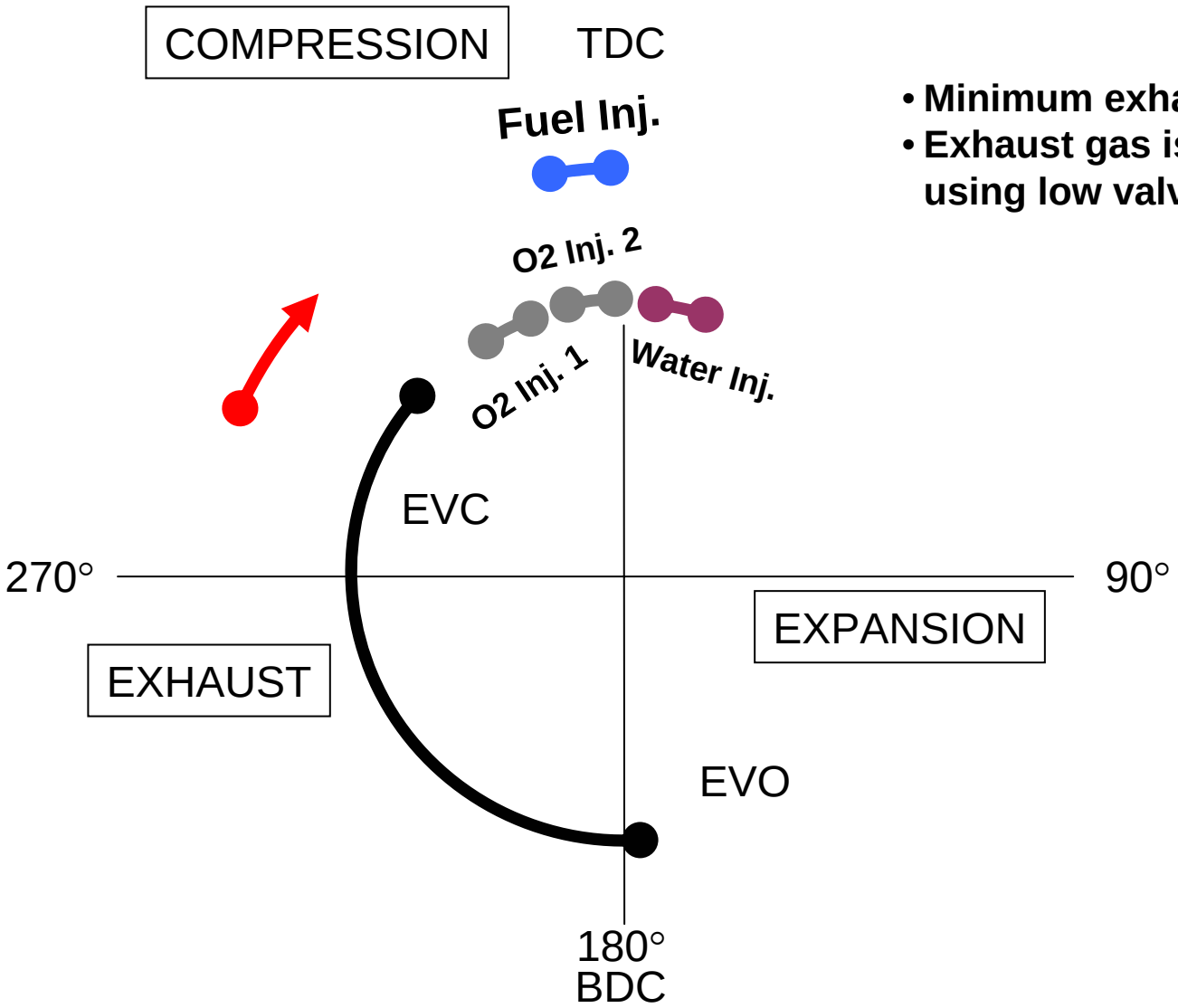
- Compression work
- Residual gas amount
- Cylinder temp. near TDC

Exhaust valve timing and lift during start up



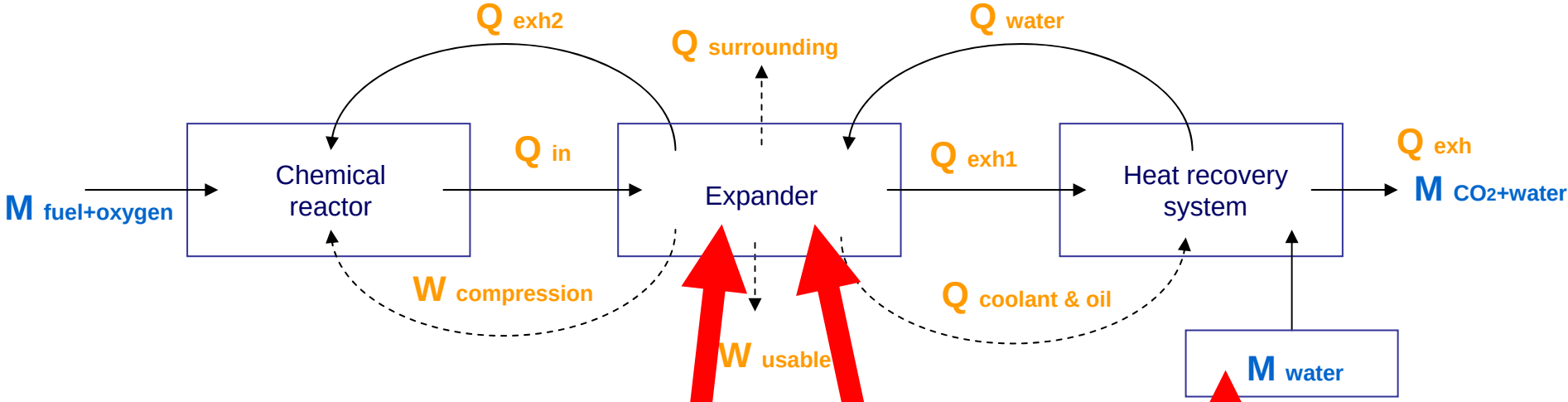
- **EVC and EVO to be overadvanced before returning to normal position**
- **Exhaust port temporarily functions as intake port**
- **Catalytic converter temporarily functions as air filter**

Exhaust valve timing and lift at idle



- **Minimum exhaust valve lift**
- **Exhaust gas is retained using low valve lift**

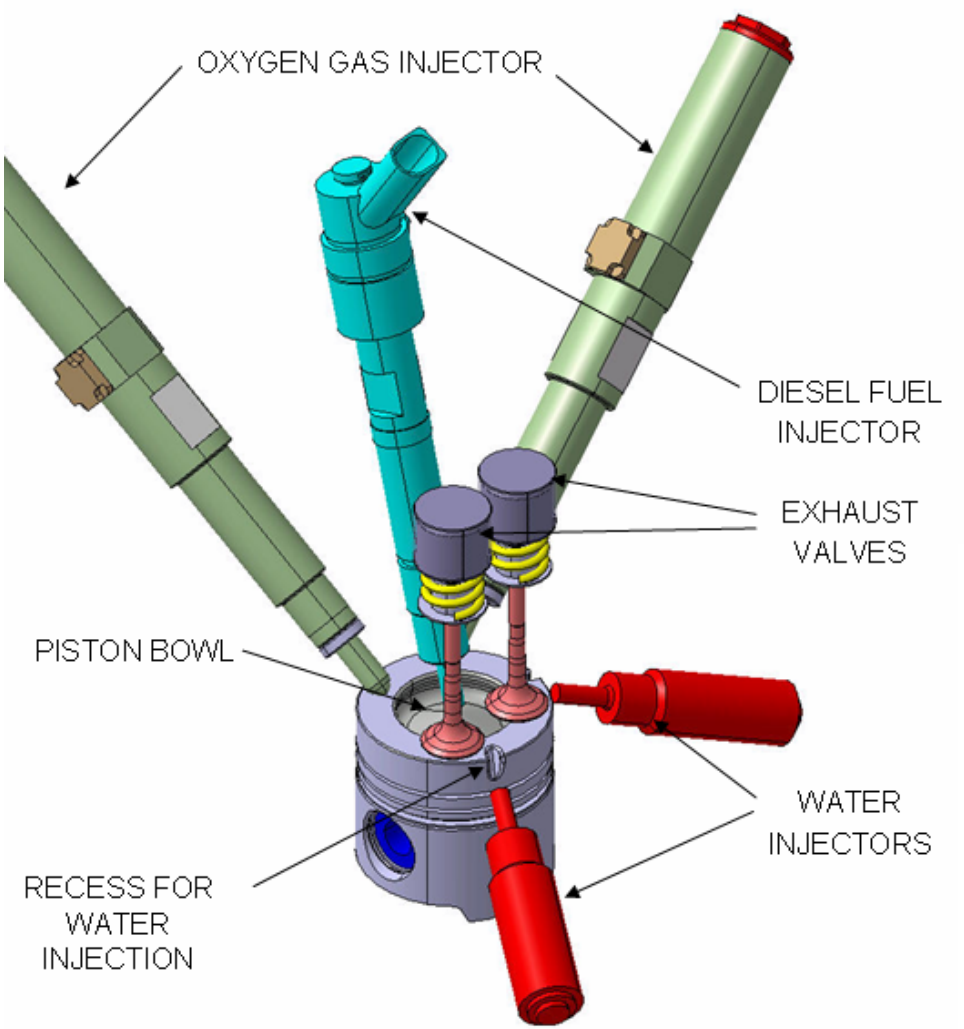
Choosing the best medium

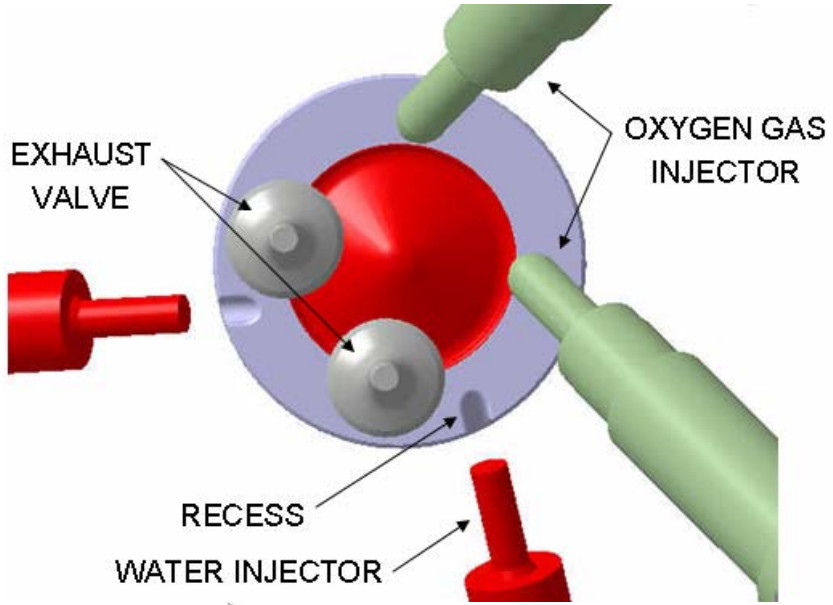


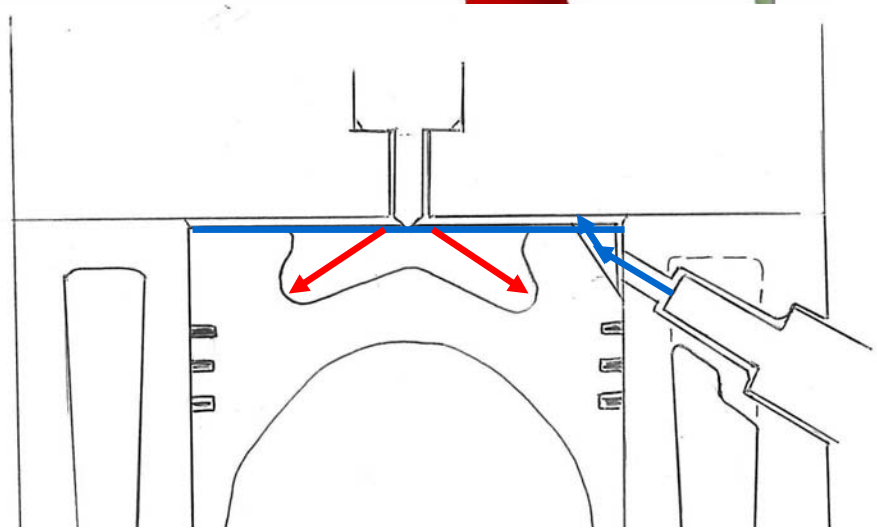
	Specific Heat Capacity (kJ/kg K)	Gas Constant R	Specific Heat Capacity (kJ/kg K)	Boiling temperature
Carbon dioxide	1.37	0.19	0.82	
Nitrogen	1.28	0.29	1.04	
Steam	2.84	0.46	2	
Water	4.8		6.8	342° Celcius

Water is a much superior working medium!

Injecting water without affecting the flame development







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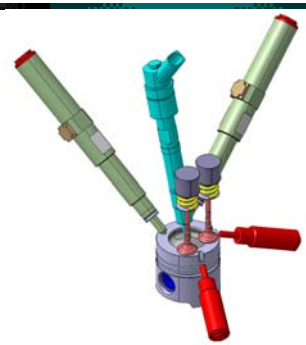
Synergizing the two energy sources and heat engines

CRUDE OIL

Chemical energy = 6100 MJ



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Charge temperature = 2000K
Cylinder pressure = 40 bar
h = 6586.5 kJ/kg

HEATED WATER

X 9.3

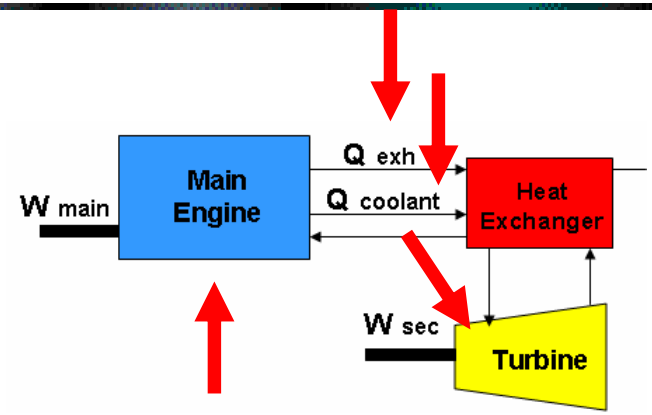
At 150 bar 330° Celcius
Thermal energy = 6100 MJ
Enthalpy (h) = 1518.6 kJ/kg

Combustion in IC engine
- High energy density
- Intense heat release
- High waste heat
- High entropy formation

Novel heat engine
- Higher enthalpy
- Single engine
- Low waste heat
- Higher output
- Low entropy

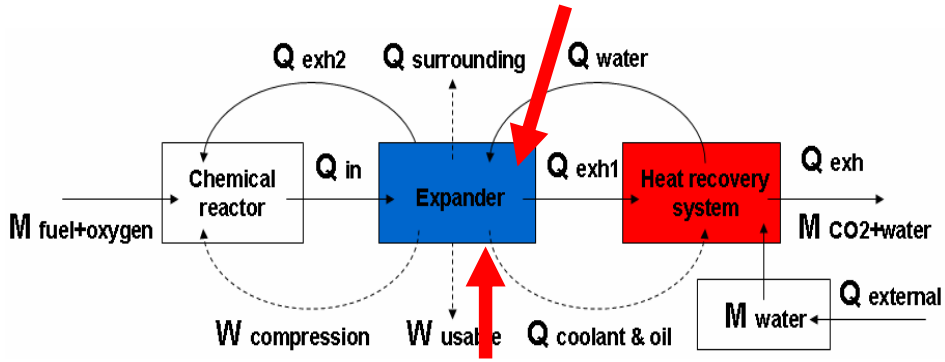
Steam engine
- Low energy density
- Low enthalpy

Comparison between Combined Cycle and Novel Cycle



Combined cycle

- 2 separate engines
- Higher secondary heat
- Higher heat losses
- Higher entropy
- Lower water enthalpy



Novel cycle

- 1 single engine
- Lower secondary heat
- Lower heat losses
- Lower entropy
- Higher water enthalpy

With equivalent energy supplied, novel cycle gives higher work output

Possible energy sources

Renewable Energy Carrier

"High grade heat"

Energy = 6100 MJ

Fossil

Bio derived

"Low grade heat"

X 25

At 1 bar and 90° Celcius
Energy = 6100 MJ
Enthalpy (h) = 377 kJ/kg

Internal heat sources
- Engine oil
- Engine coolant

External heat sources
- Sunlight (low grade)
- Industrial waste heat
- Bearings

Serial heating

"Medium grade heat"

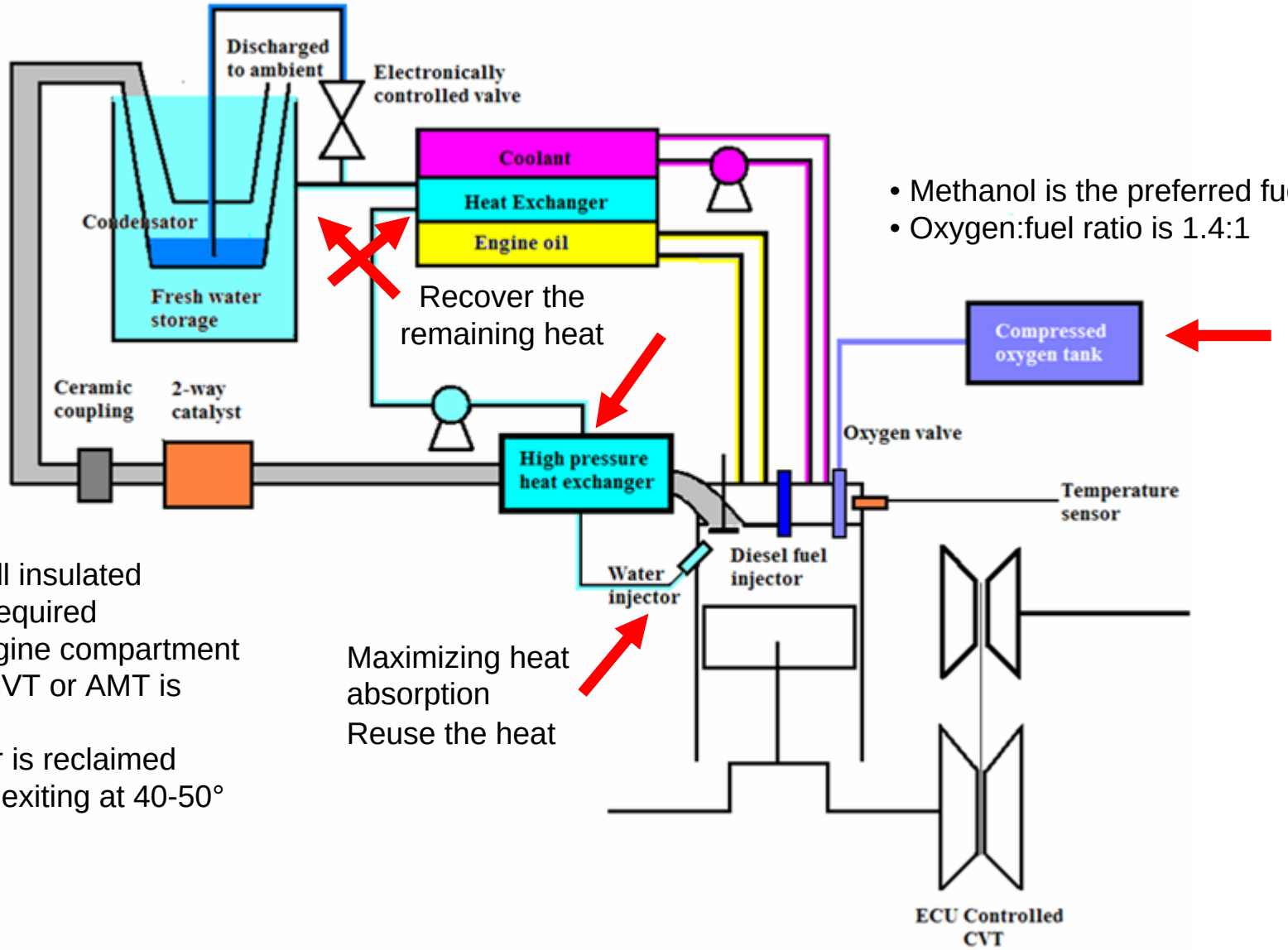
X 9.3

At 150 bar 330° Celcius
Energy = 6100 MJ
h = 1518.6 kJ/kg

Internal heat source
- Exhaust gas

External heat sources
- Geothermal
- Brake system
- Steam power plants
- Sunlight (concentrated)

Novel heat engine for land transportation application

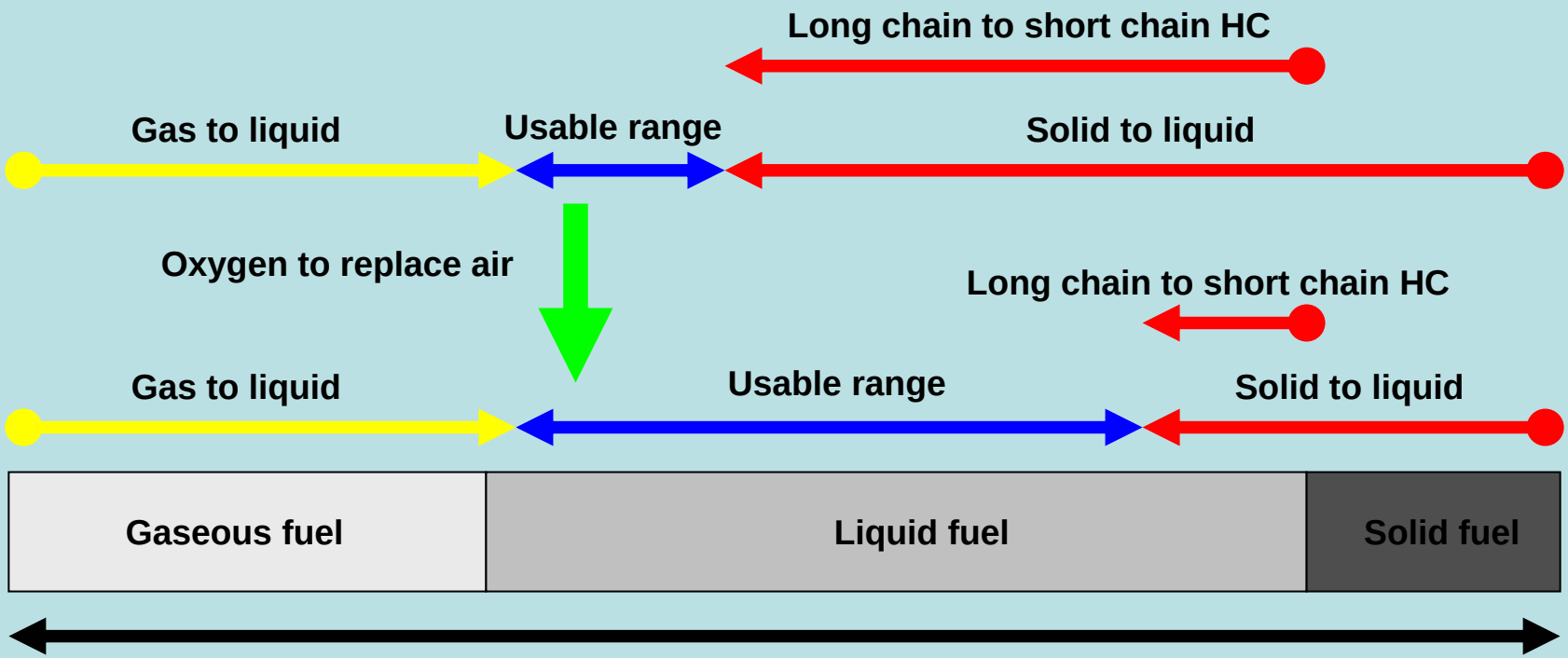


- Methanol is the preferred fuel
- Oxygen:fuel ratio is 1.4:1

- Parts are well insulated
- No radiator required
- Enclosed engine compartment
- Large ratio CVT or AMT is needed
- 80% of water is reclaimed
- Exhaust gas exiting at 40-50° Celcius

Observed trend of fuels for heat engines and furnaces

With oxygen, broader range of fuels is now possible!



Left extreme

- Shorter HC chain
- Lower density
- Lower energy per volume
- Lower sulfur content
- Easier to burn completely

Right extreme

- Longer HC chain
- Higher density
- Higher energy per volume
- Higher sulfur content
- Harder to burn completely

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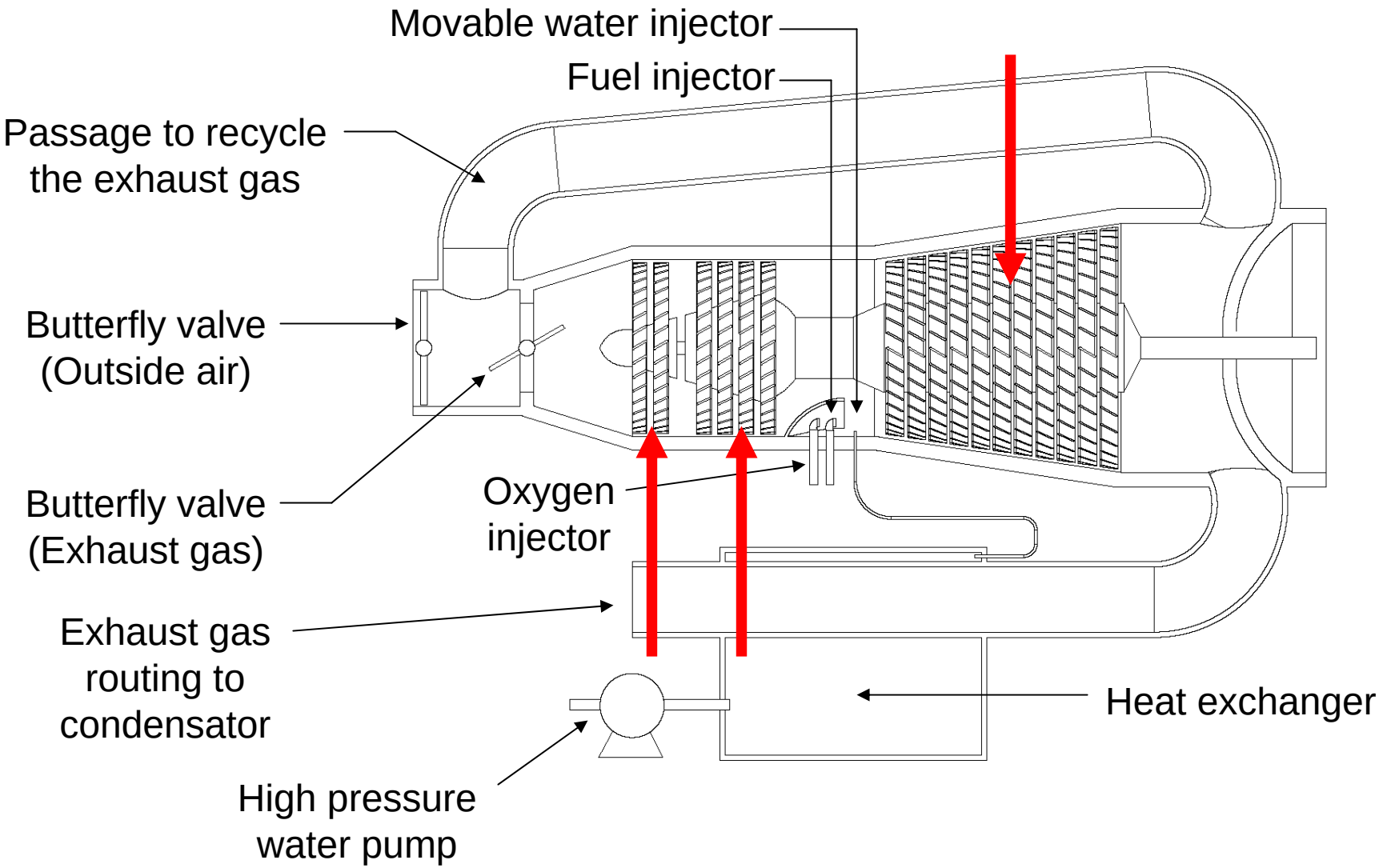
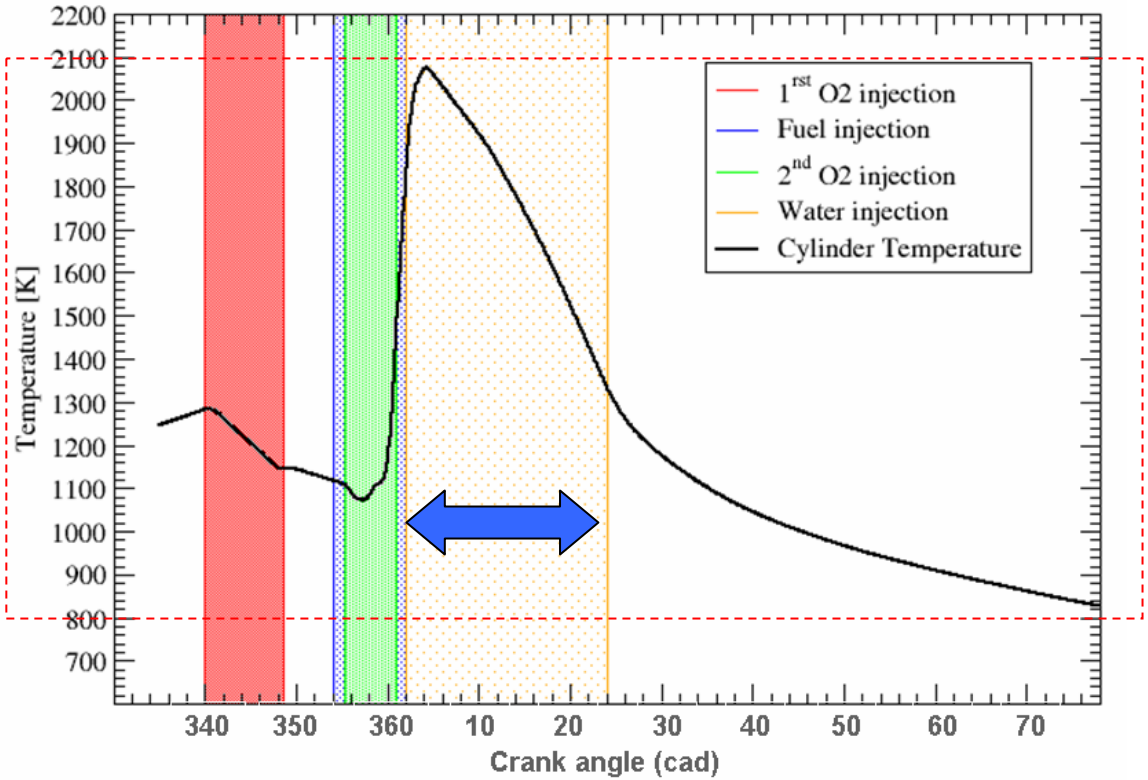
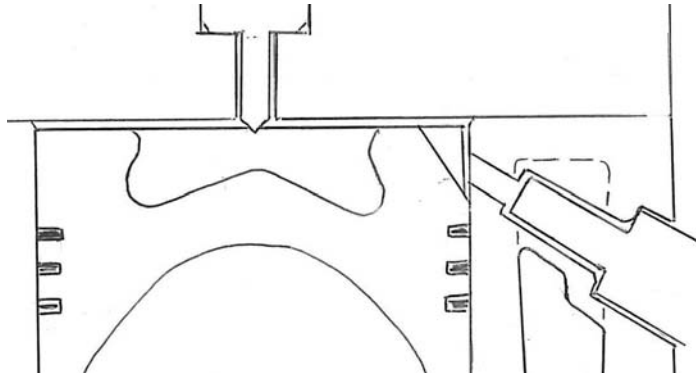
Application in gas turbine



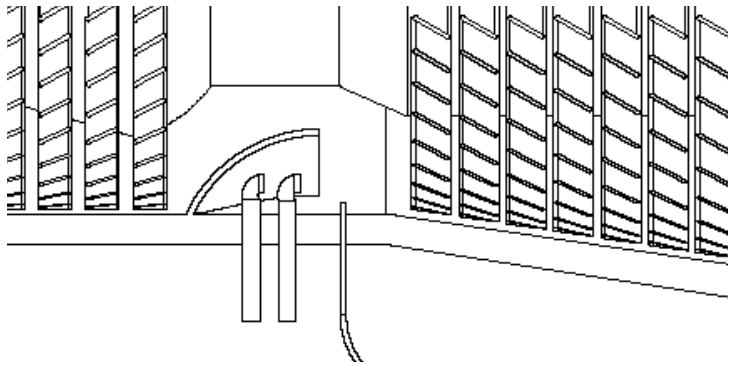
Liquid waste disposal



Cylinder temperature plot



Piston engine

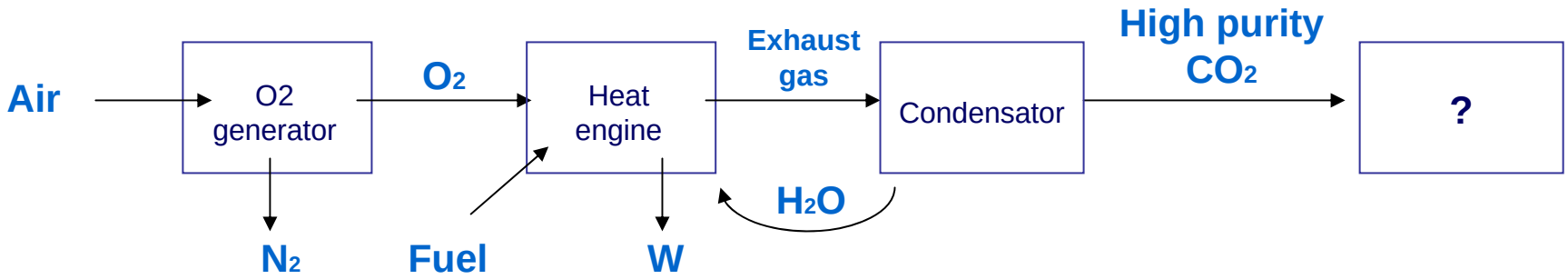


Gas turbine

High cylinder temperature for disposal of: -

- Industrial wastewater
- Oil processing wastewater
- Biohazard

Value adding exhaust gas?



?

- Enhanced oil recovery (EOR)
- Enhanced coal bed methane recovery
- Carbon dioxide sequestration
- Algae production for biofuel

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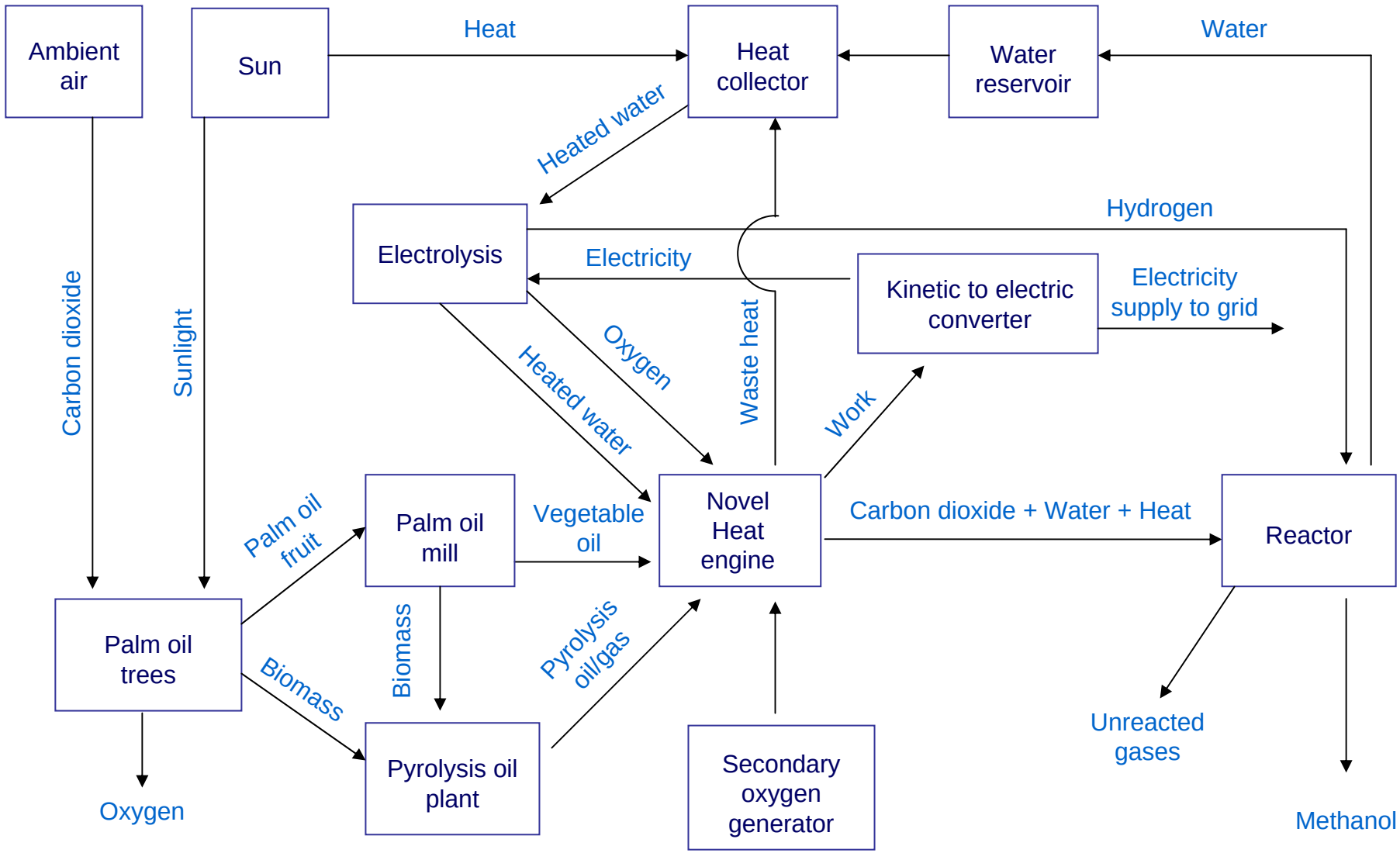
Integrated Power and Fuel Generation Plant



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Conclusions

- Innovative water injection system enables: -
  - Direct cooling of combustion chamber
  - Maximum absorption of combustion heat
  - Recovery of the remaining secondary heat
  - Reuse of the recovered secondary heat
  - Carrying thermal energy from outside into the system
  - High overall engine efficiency is now possible

- Novel heat engine gives the best work output by combining both combustion engine and steam engine

- High purity carbon dioxide from the exhaust gas can be used for: -
  - Carbon dioxide sequestration
  - Enhanced oil/gas recovery
  - Methanol production

Conclusions (cont.)

- High temperature water heating enables liquid waste disposal
- Stratification of oxygen and fuel enables broader options for usable liquid and gas fuels lowering both fuel processing costs and energy usage
- Regulated emissions and SO x can now be addressed through more effective means
- Carbon dioxide discharged is reduced by
  - Minimizing the CO2 generation
  - Turning the CO2 into methanol
  - Sequestration of high purity CO2
- Energy sustainability is possible in the future by using integrated power and fuel generation plant

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"The best way to predict the future is to invent it",
quoted from Alan Kay, a former Xerox researcher

Thank You