

Fifth Annual Conference on Carbon Capture & Sequestration

Steps Toward Deployment

Oxy-Combustion

**Forcing of zero emissions piston engine by oxygen enrichment
in membrane reactor
(Hi-Ox ZEMPES project)**

Mikola Shokotov, Evgeni Yantovski and Kirsten Foy

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ZEMPES – an Oxycombustion vehicle

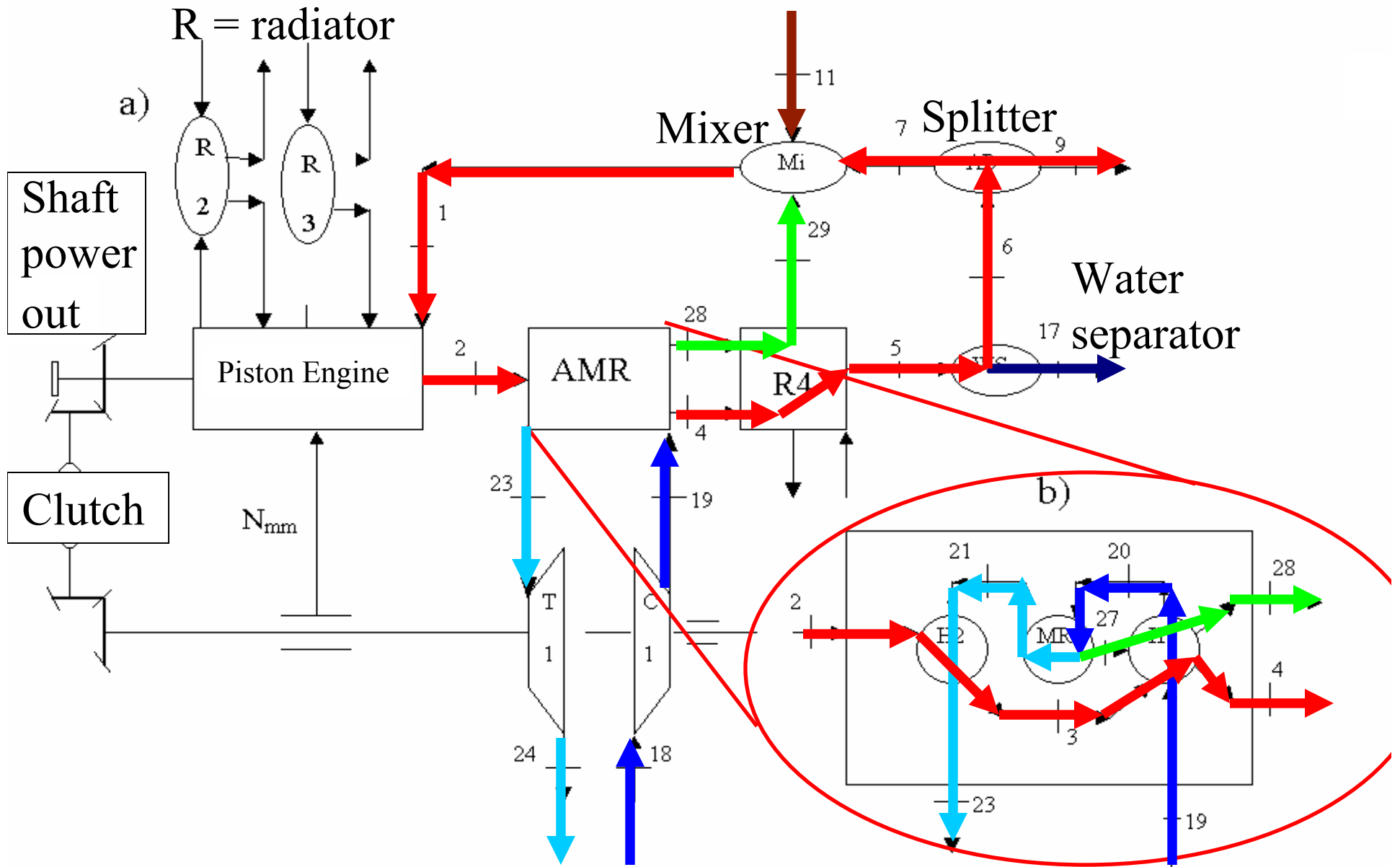
- Zero Emissions Membrane Piston Engine System
 - OTM separates oxygen from air
 - Oxygen mixed with CO₂
 - Fuel burned with this mixture in piston engine
 - Exhaust contains only CO₂ and H₂O
 - Cooled → water removed
 - CO₂ compressed and stored onboard
 - Eject CO₂ at fuel filling station

Oxygen Ion Transport Membranes (OTMs)

- Solid membranes made of special ceramics
- Ceramic lattice contains oxygen ion vacancies
- Above $\sim 700^{\circ}\text{C}$ oxygen ions can travel through
 - Acts like a sieve for oxygen
 - If incorporated into cycle: uses very little energy

ZEMPES layout

- Air
 - Compressed and Heated
 - Some oxygen removed
 - Expanded and Exhausted
- Piston engine exhaust
 - Cooled – water removed
 - Some CO₂ recirculated to piston engine
 - Some CO₂ stored for sequestration



Air
 Oxygen
 Depleted air
 Fuel
 Water
 CO₂ or mixture containing CO₂

ZEMPES

- Proportion of oxygen in mixer can be altered
- Previous papers assume oxygen fraction = 0.21
 - Efficiency = **34%**
 - Base case
- Hi-O_x ZEMPES – increase oxygen fraction
 - Does not require any change in layout

Hi-O_x ZEMPES

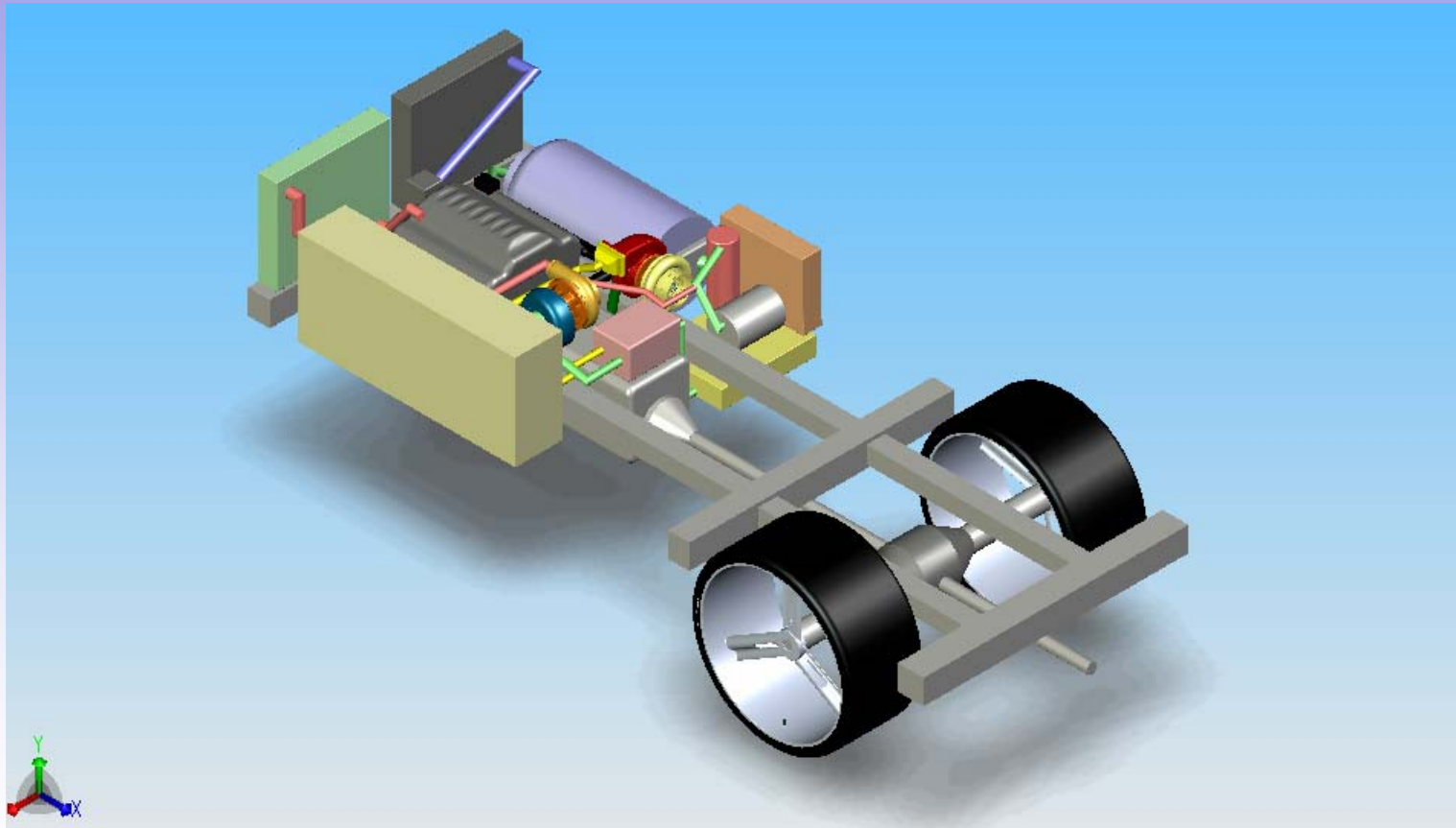
- Smaller engine required
 - at 0.209, 6 cylinders needed
 - at 0.4, only 3 cylinders for same power

Oxygen fraction in mixture	0.209	0.3	0.4	0.5
Efficiency	34%	38%	39%	40%
Temperature of exhaust [K]	830	1072	1319	1575

Further improvement

- Efficiency increases with oxygen content
- Heat is lost at very high temperatures
 - Good quality heat
 - Use heat to further increase efficiency
- Previous work
 - Supercharging turbine
 - Bottoming Rankine cycle
 - Complicate system

ZEMPES with supercharger



Thermochemical Recuperation

- TCR
- Physically simpler – like a heat exchanger
- No moving parts
- Uses heat of exhaust to convert fuel and water to syngas
- Endothermic reaction
 - Adds energy to fuel before it enters engine
 - Increases efficiency

Hi-O_x ZEMPES with TCR

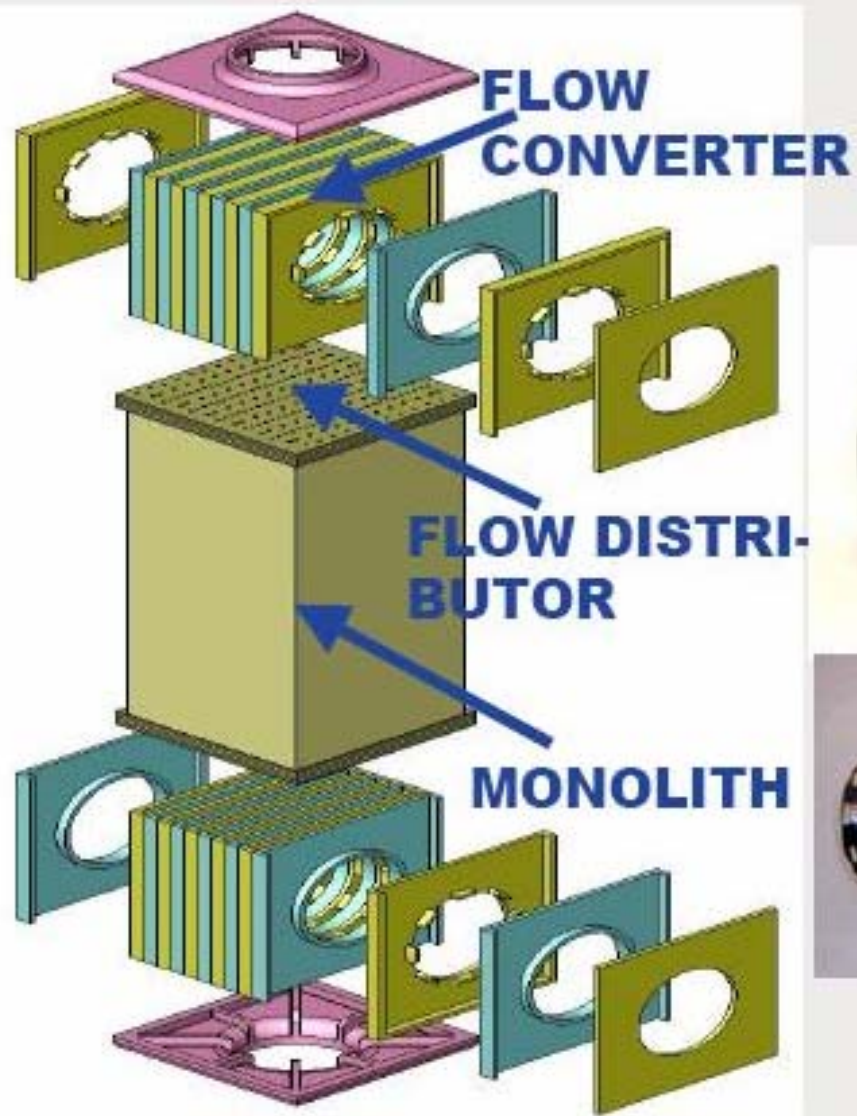
Oxygen fraction in mixture	0.209	0.3	0.4	0.5
Efficiency	34%	42%	42%	43%
Temperature of exhaust [K]	816	970	1149	1295

Hi-O_x ZEMPES with TCR and increased pressure ratio in turbocompressor

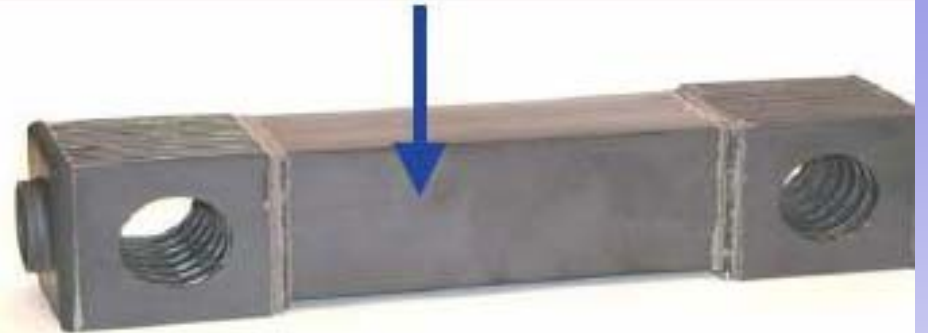
Oxygen fraction in mixture	0.3	0.4	0.5
Pressure ratio	3	5	9
Efficiency	42%	44%	47%

Emissions? Zero emissions

- None of the products of combustion are released to atmosphere
- Any impurities in fuel become impurities in sequestered carbon dioxide
- Hot air with some oxygen removed is only “emission”
- Air not heated to NO_x forming temperature
- There are no emissions



**ASSEMBLED CERAMIC
MEMBRANE MODULE
FABRICATED BY HYDRO**



**ASSEMBLED CERAMIC
HEX MODULE
FABRICATED BY HYDRO**

ZEMPES prototype

- Vehicle manufacturers concentrate on fuel cell and hydrogen vehicles – billions spent
- ZEMPES – theoretically 47% efficiency
- Components required are available
- It is time for a ZEMPES prototype