

Turbomachinery Development for Electrification of Industrial Process Heating

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Industrial Process Emission Reduction (IPER) Technology
Workshop, March 1-2, 2023



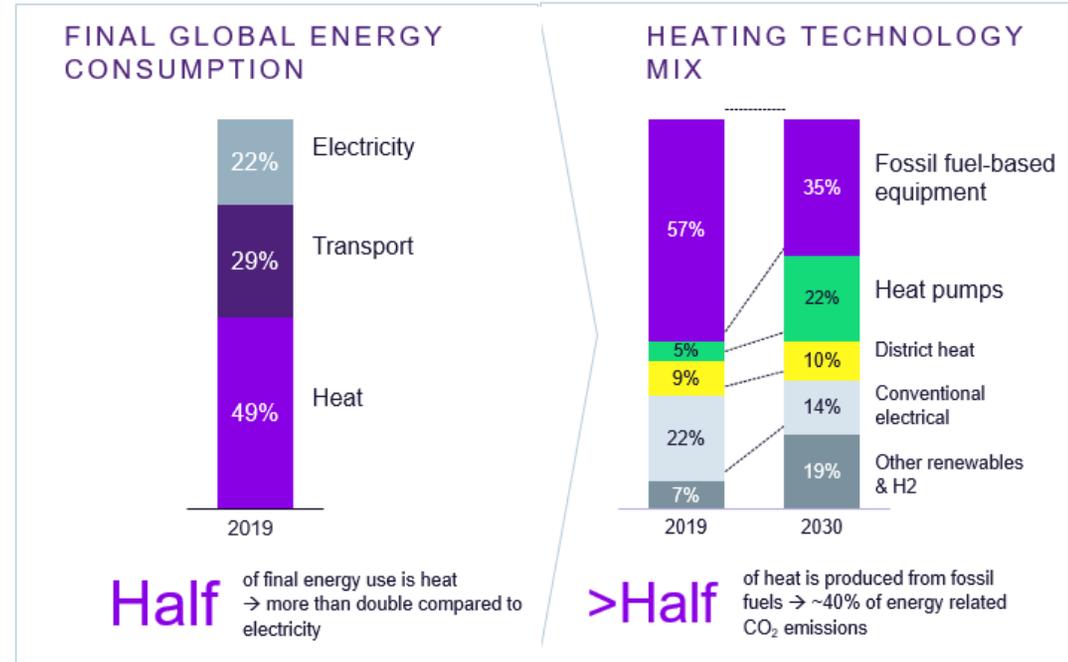
Industrial Heating Landscape



TECHNIP
ENERGIES

SIEMENS
energy

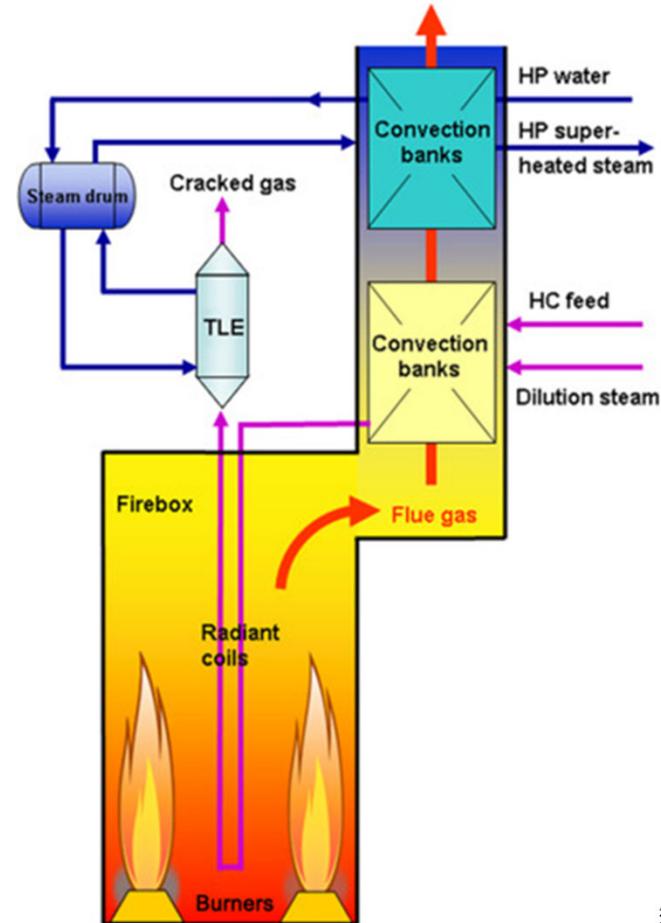
- Not news, but industrial heating is major final use of energy in world economy
- Options for decarbonization vary, mainly with process temperature
 - Low temperature (<200°C)
 - Building heating, district heating, some industrial processes (steam drying)
 - Heat pump technology fits well, high CoP
 - Medium temperature (200 – 500°C)
 - Majority of petrochemical sector
 - Heat pump can apply, better with scale
 - Cascaded cycles such as reverse Brayton
 - High temperature (>500°C)
 - Steel making, olefins production, cement...
 - Possibilities include resistive heating, hydrogen firing, post-combustion carbon capture
- Missing turbomachinery solution for upper medium temperature and high temperature applications



Source: IEA / IRENA 2020 (Renewable Energy Policies in a Time of Transition, Key World Energy Statistics). All rights reserved.

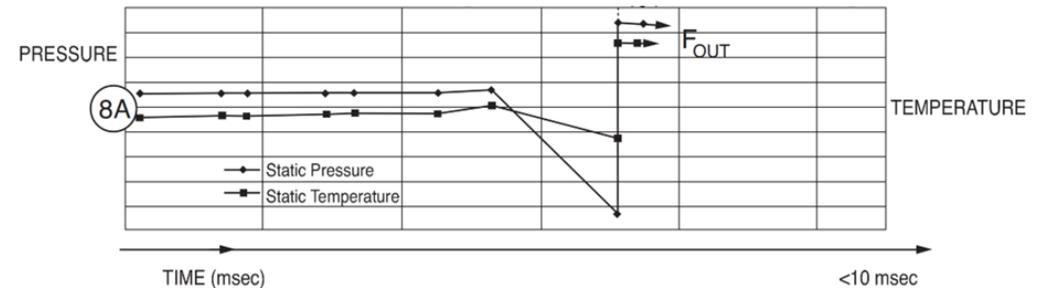
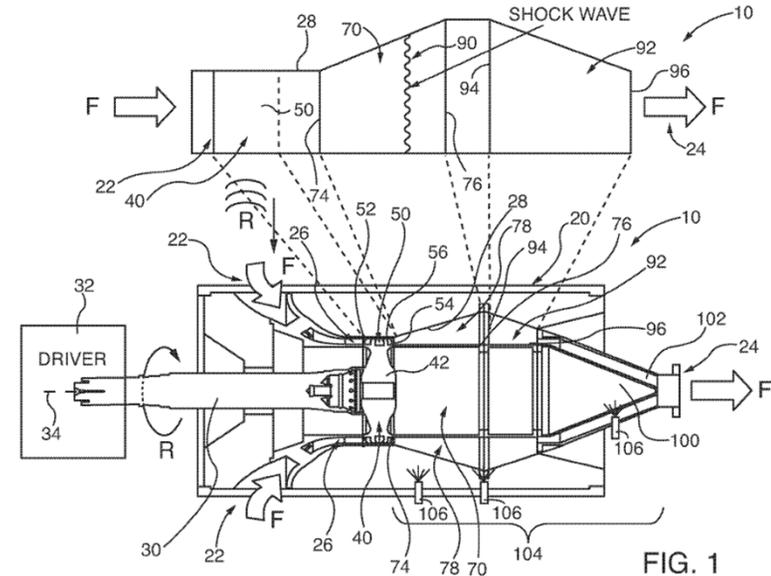
Consider the Olefin Process to Make Ethylene...

- Radiant furnace is core to the current industry standard
 - Typical furnace temperatures 1100-1200°C
 - Fuel is mainly hydrogen and light hydrocarbons
 - “Waste heat” is also utilized for pre-heating feedstock and for generating steam
- Decarb options include burning pure hydrogen
 - Must have external source of hydrogen
 - Blue H2 carries CO2 sequestration burden
 - Green H2 carries cost and scalability burden
- Can also do CO2 capture from furnace
 - Significant cost driver
 - Feasibility questions (nearby CO2 sequestration? Scalability?)
- There is room for another solution

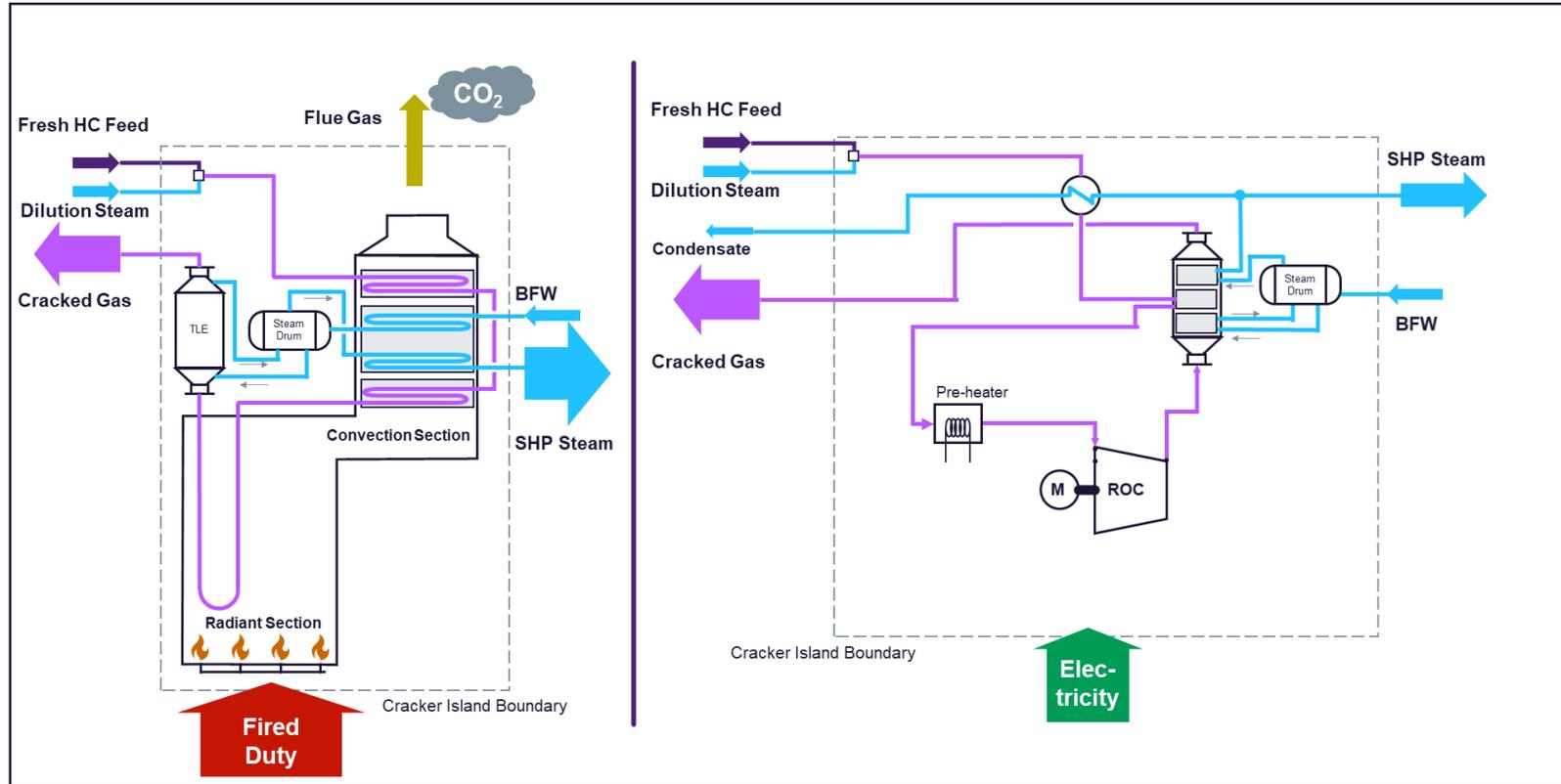


Development of Shock Wave Heating

- Siemens Energy and Technip Energies working on Joint Development Agreement (JDA) to commercialize the Rotating Olefin Cracker (ROC)
- Fundamental concept
 - Increase working fluid temperature with a shock wave
 - Steam/ hydrocarbon mix enters machine, is accelerated by impulse type stages to supersonic velocity, then decelerated in the diffuser section which hosts the shock wave
- Important characteristics of a turbomachine
 - **Driver agnostic** – pure process electrification if driven by motor, but can be driven by turbine as well
 - **Scalable** – larger heat capacity requires only modest increase in machine size
 - **Direct application** of heat to working fluid

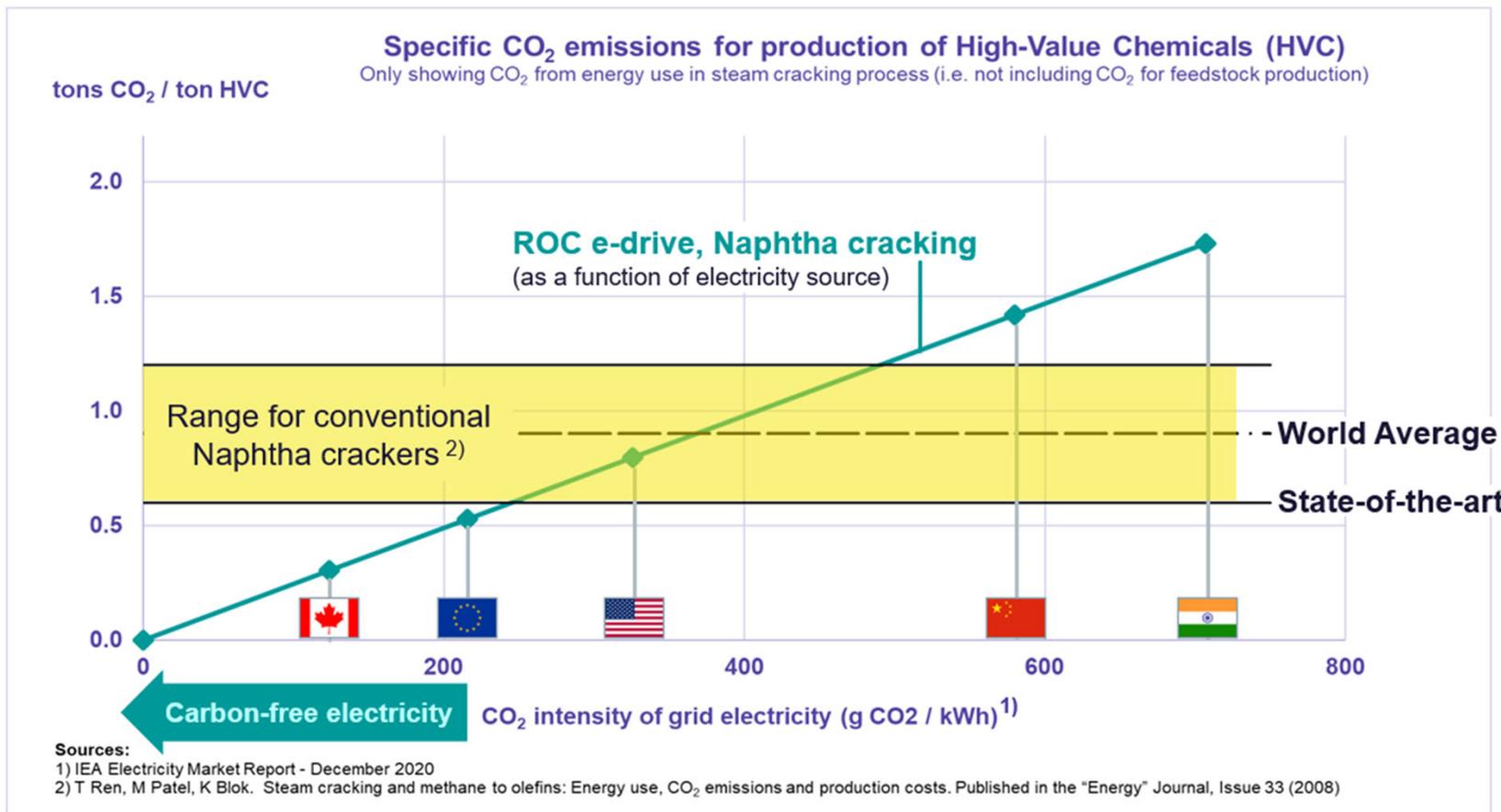


Olefin Process, Before and After ROC

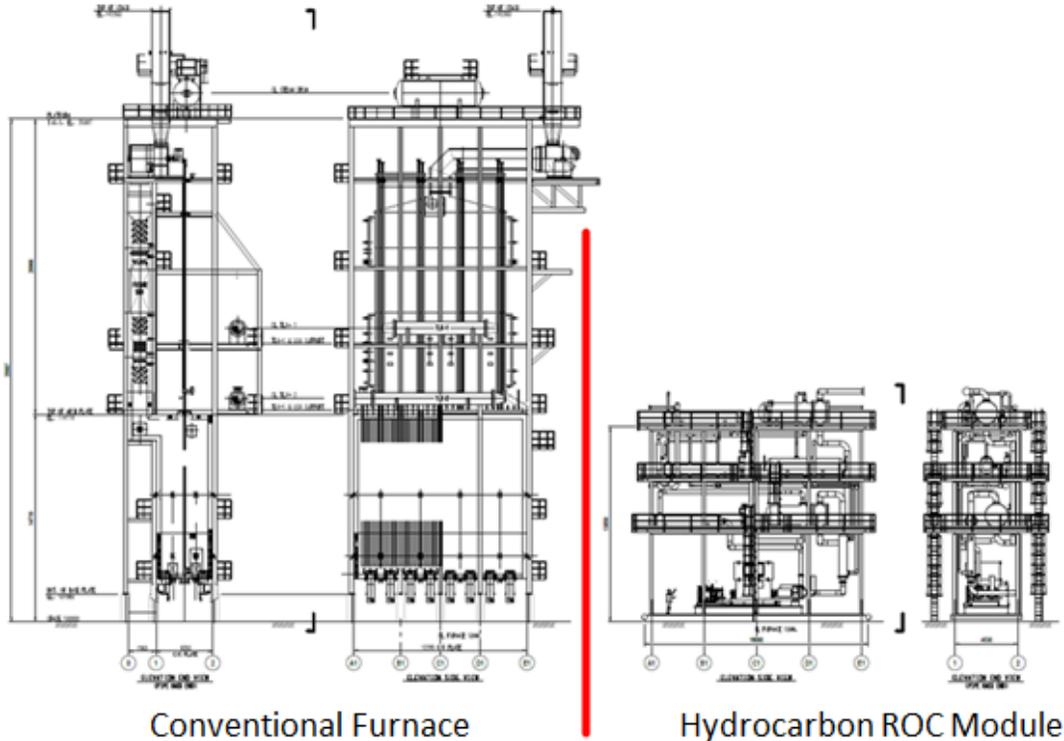


Motor driven ROC with electric pre-heater eliminates all CO₂ emissions from the furnace

ROC Enables Substantial GHG Reductions

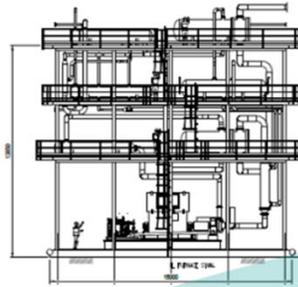


ROC Technology Has CapEx and OpEx Benefits



- Significant footprint reduction due to compact method of imparting heat to the feedstock
- Turbomachinery based solution scales up well, doubling output for much less than double the equipment size
- Near instantaneous heating leads to smaller/ optimized reaction volumes – improved yield
- No surface heat exchange, minimizing potential to form carbon deposits which reduce capacity of system

ROC Technology Development Path



Shock Tube Test
Shock Wave Cracking
TRL 3



Air Demonstrator
ROC Turbomachinery
TRL 4



Hydrocarbon Demo
Operating Cracker Site
TRL 7 & TRL 8



Commercial Deployment
Brownfield & Greenfield
TRL 9

Shock Tube Testing Validates Chemistry of Shock Wave Cracking

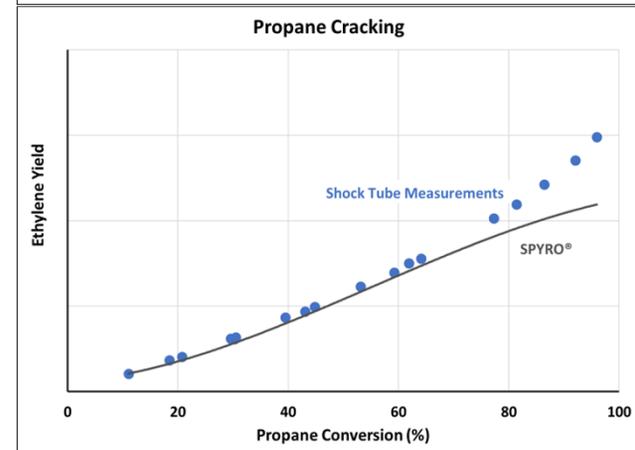
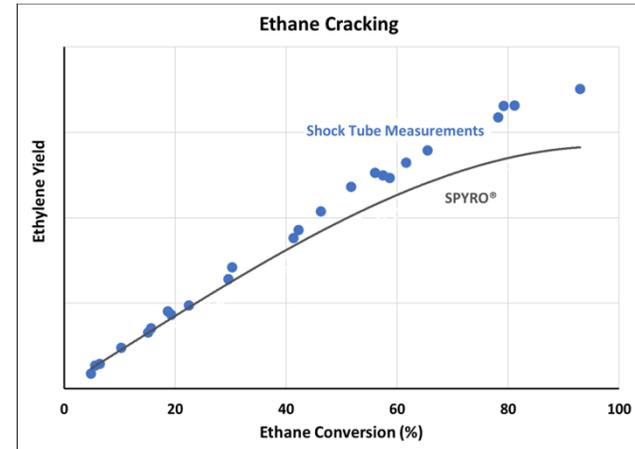


- Testing performed in existing facility at Stanford University under the direction of Dr. Ron Hanson
 - Varying mixtures of hydrocarbons and inert gases
 - Optical methods used to monitor resulting gas species

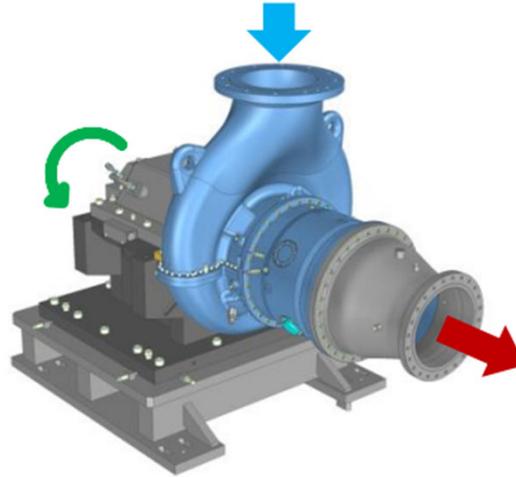
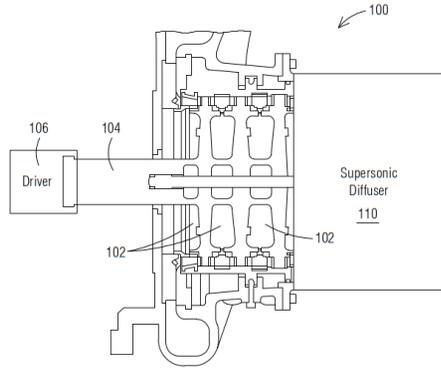
- Rig also used to evaluate soot formation
 - No detectible soot formed near ROC conditions

- Results used for validation of SPYRO at these timescale conditions
 - SPYRO generally in agreement with measurement results
 - Post-test analysis signals higher process yields for ROC based system as compared to conventional:

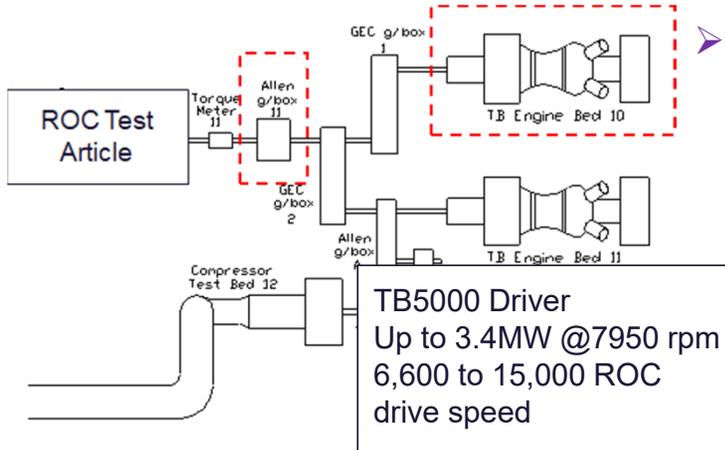
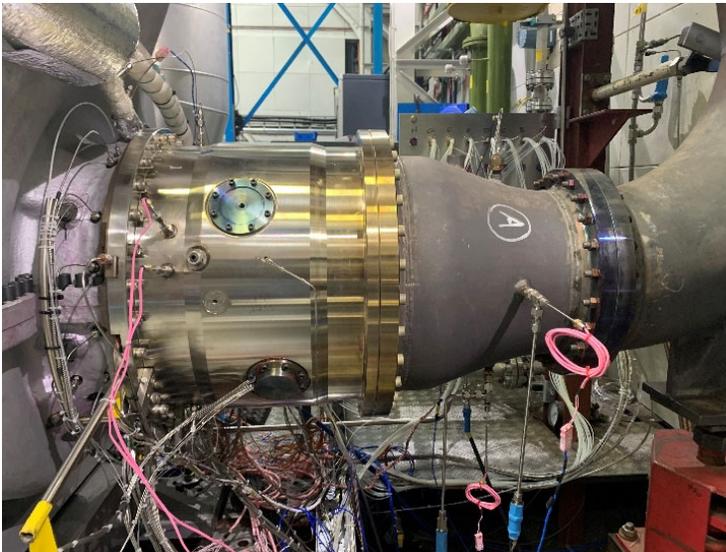
	90% Propane Conversion Yields Ratio	Naphtha P/E=0.42 Yields Ratio
Ethylene	1.09	1.06
High Value Chemicals	1.07	1.04



Air Demonstrator Test Performed at SE Lincoln, UK



- Patent image reflects basic geometry tested
- CAD model of actual test article
- Photo of rig in Lincoln test stand (Firth Road Facility)

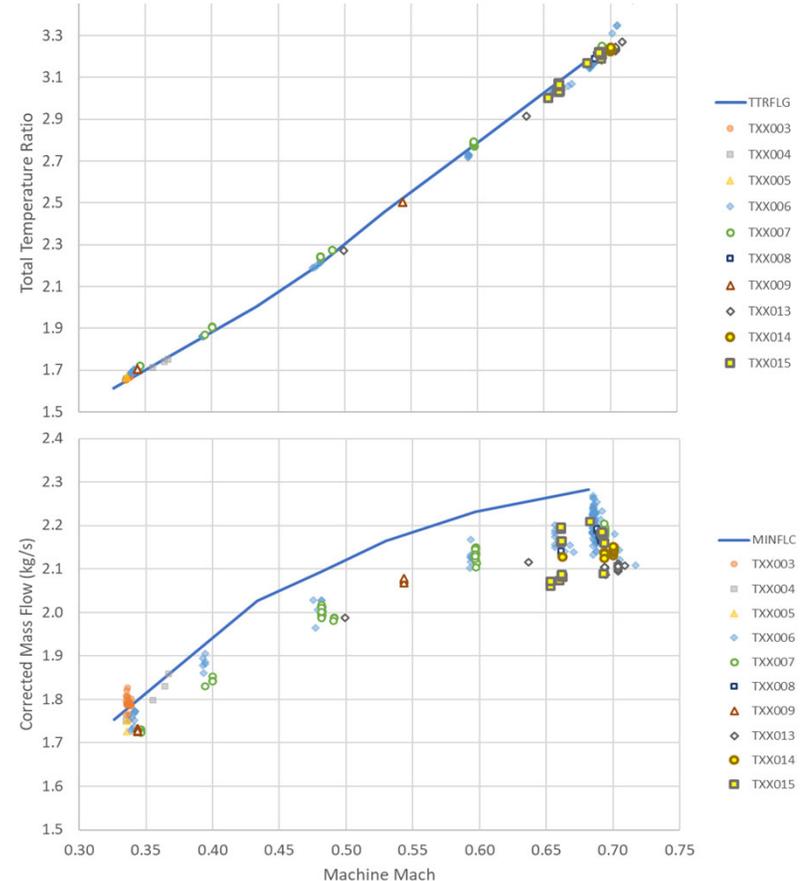


- Schematic of drive system
 - Gas turbine driver
 - Two gear boxes

Test Demonstrates Expected Temperature Ratio



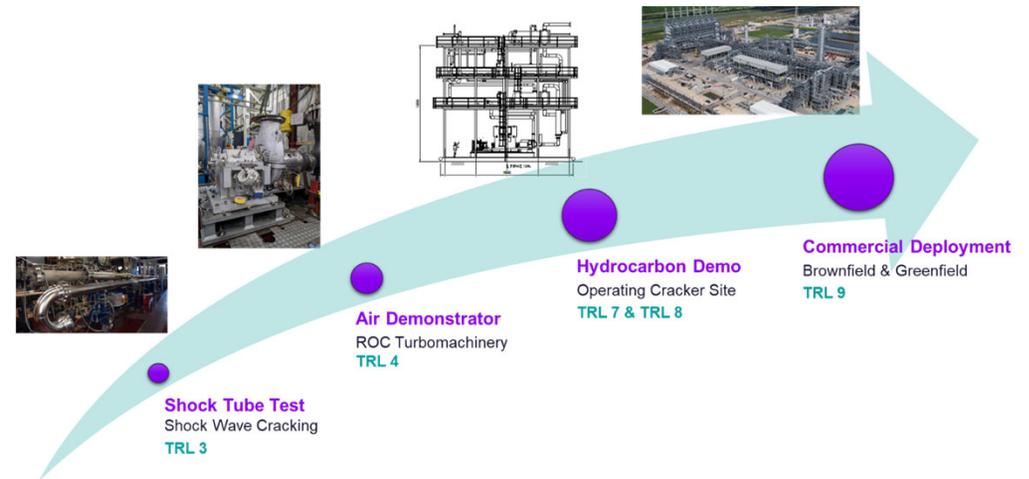
- Test campaign scheduled for August – October, 2022
 - Actual start date, August 8th
 - Completed all testing September 1st
- Pre-test prediction for temperature ratio as function of machine Mach number (i.e. speed)
 - Blue line on graph, showing maximum temperature ratio for this design as about 3.3
- Test results indicated with points on the same graph
 - Excellent agreement with pre-test temperature ratio predictions
- Corrected mass flow results demonstrate a 4% shortfall compared to pre-test predictions
 - Most likely cause is unforeseen internal leakage from interior cooling circuits
- Rotordynamic performance as-expected
- Successful completion of API 4-hour mechanical run test with varying rotor speed, lube oil temperature and lube oil pressure



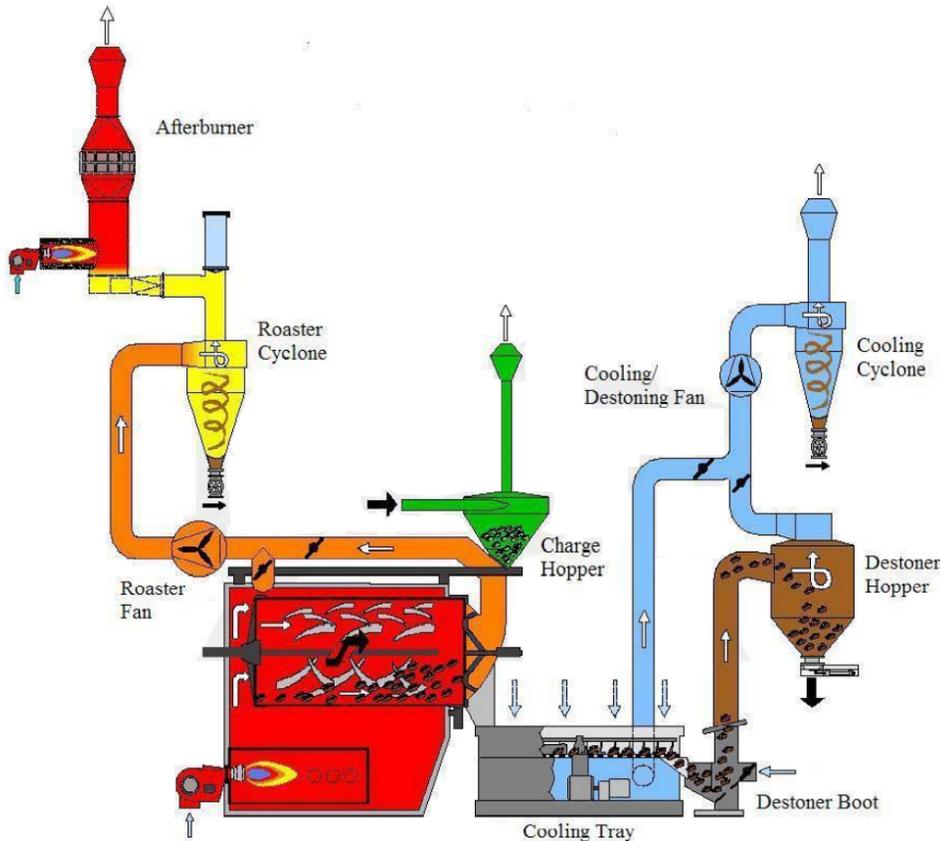
ROC Development Continues with Hydrocarbon Demo



- Focus of SE/ T.EN team is currently on the design of the hydrocarbon demo
 - Turbomachinery + auxiliaries
 - Balance of plant with static equipment, heat exchangers, quench, etc.
- Working to identify an ethylene plant partner as demo site for first cracker unit
 - Currently working with the Cracker of the Future Consortium on demonstration test program (non-exclusive MOA)
- As if hydrocarbon cracking is not enough to consider, what about...



The Coffee Bean Roasting Process?



- Process which depends heavily on hot air from combustion devices
- Hot air required at two locations in system (roaster oven and afterburner)
- Similar to hydrocarbon cracking, other forms of decarbonization include
 - Resistive heating (does not scale like turbomachinery)
 - Green fuel burn (challenge of obtaining enough, affordable green fuel)
- TurboHeater form of ROC can do this service
 - Essentially the air demo in a commercial package
- SE currently looking for industrial demo partners

Thanks for your attention...

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