An Evolutionary Approach to Very High Efficiency Methanol Engines for Maritime Applications+

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First Phase

Spark Ignition engine with similar efficiency to diesel engine:

- Uses established engine technology
- Very low emissions
- Option for operation as compression ignition engine that operates entirely on diesel

Second Phase

Use “Reformer based” exhaust heat recovery

In spark ignition engine:

- Increase efficiency by up to 25 %
- Enhance economic attractiveness
- Reduce greenhouse emissions
- Option for operation entirely on diesel fuel as compression ignition engine

Spark ignition (SI) Engine

- Ignition of premixed fuel and air by flame propagation from an electrical discharge (Otto cycle)

- Can operate with stoichiometric fuel/air ratio
  - Lower emissions than diesel engine
  - More effective energy recovery (higher exhaust temp)

- Ignition can alternatively be provided by use of a small amount of diesel fuel (pilot compression ignition)

Diesel-Like High Efficiency In SI Engine

- High octane of methanol prevents knock (unwanted detonation) that limits performance of spark ignition engine
- Allows high compression ratio and high level of turbocharging / engine downsizing (40% smaller size than diesel with same efficiency and torque)
- Diesel –like high efficiency demonstrated in engine tests using port fuel injection (EPA Ann Arbor)
- Additional performance and efficiency improvement using octane enhancement from direct injection or open-valve port fuel injection (MIT)

Emissions

- Spark ignition engine uses low cost and highly effective three way catalyst (TWC) to reduce pollution to very low levels

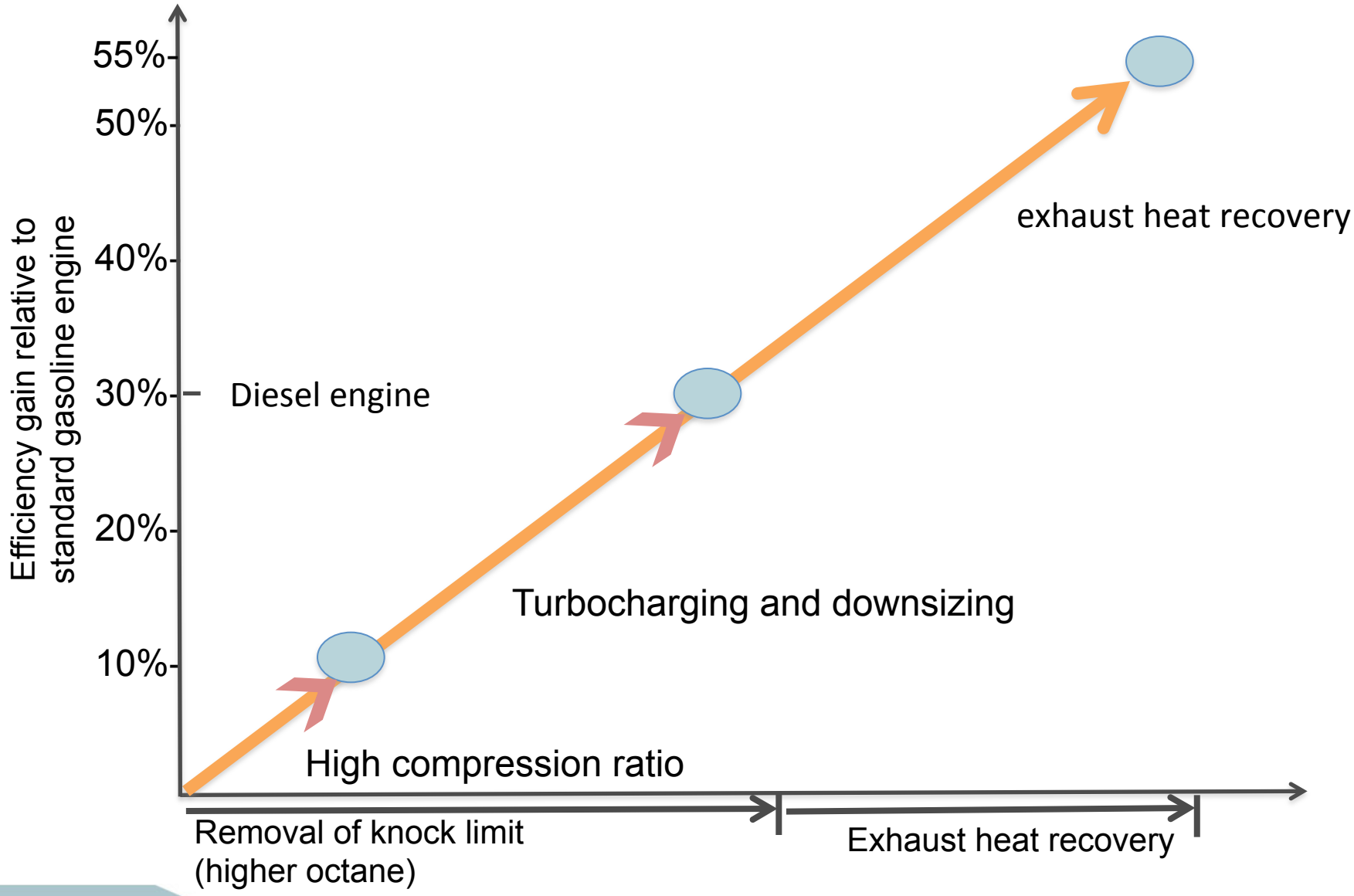
- Diesel engine without particulate and NOx exhaust after -treatment produces very high pollutant levels

- Clean diesel engine uses complex and expensive exhaust gas treatment system (urea SCR + particulate filter) to substantially reduce pollution (but it is still not as low as spark ignition engine)

Spark Ignition Methanol Engine With Option For Diesel Operation

- Relatively simple modification of diesel engine
  - Add port fuel injector for methanol
  - Add spark plug (or use diesel pilot ignition)
  - Use fuel from methanol tank or diesel tank
  - Option for operating entirely on diesel fuel

Super -efficient Spark Ignition Methanol Engines



MIT Optimized Waste Heat Recovery

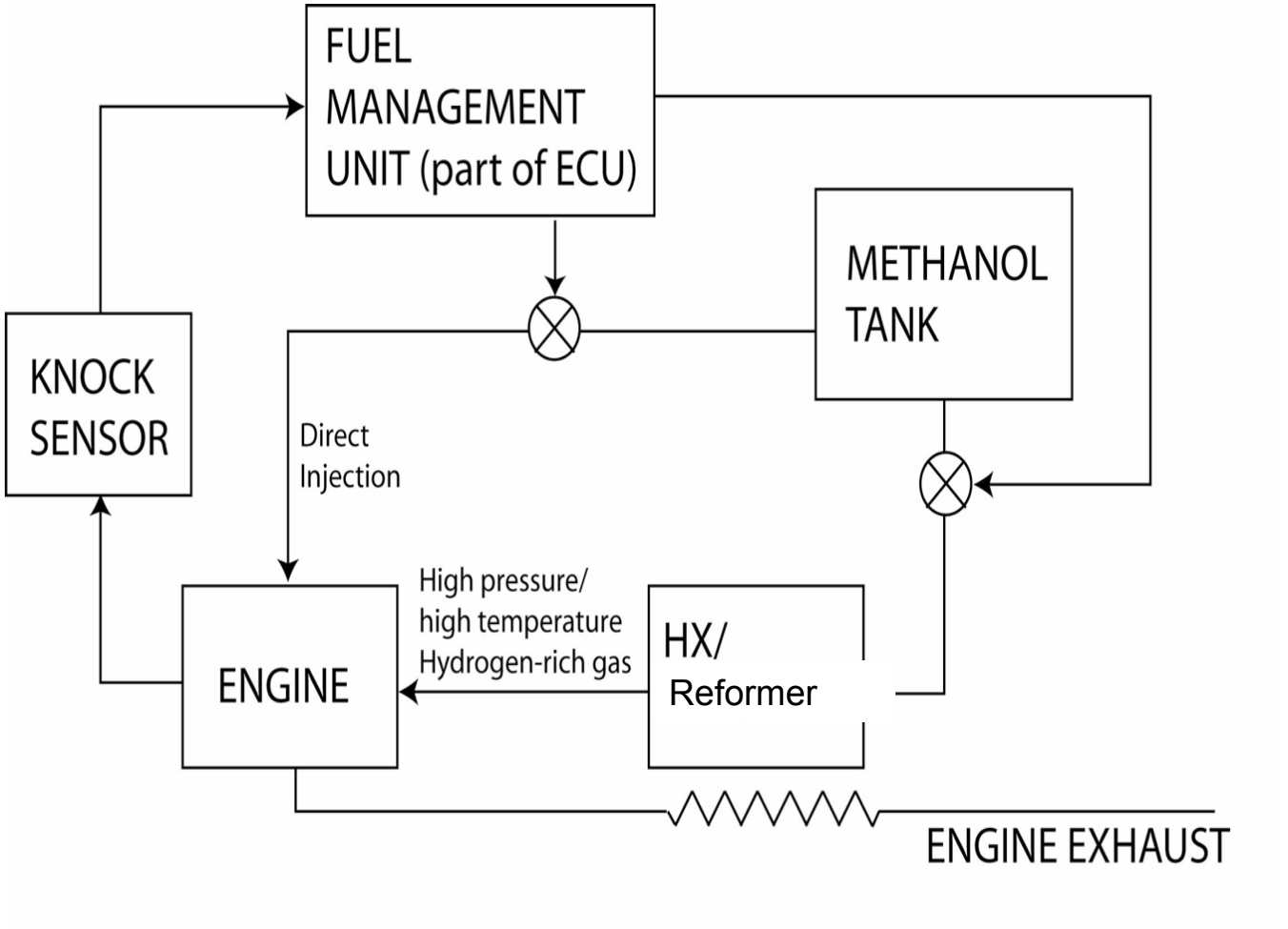
1. Spark ignition engine
   (stoichiometric fuel/air ratio provides higher exhaust temperature and better heat transfer than diesel)

2. Reform methanol into hydrogen-rich gas that has more chemical energy and is then combusted in engine

3. Open Rankine cycle: further increase heat recovery

4. Metallic foam heat exchanger

Waste Heat Recovery by Reforming Methanol



Low temperature catalytic reforming

$CH_30H \longrightarrow 2H_2 + CO$ (syngas)

Endothermic decomposition

Syngas has more energy than methanol

Methanol Injection at High Load

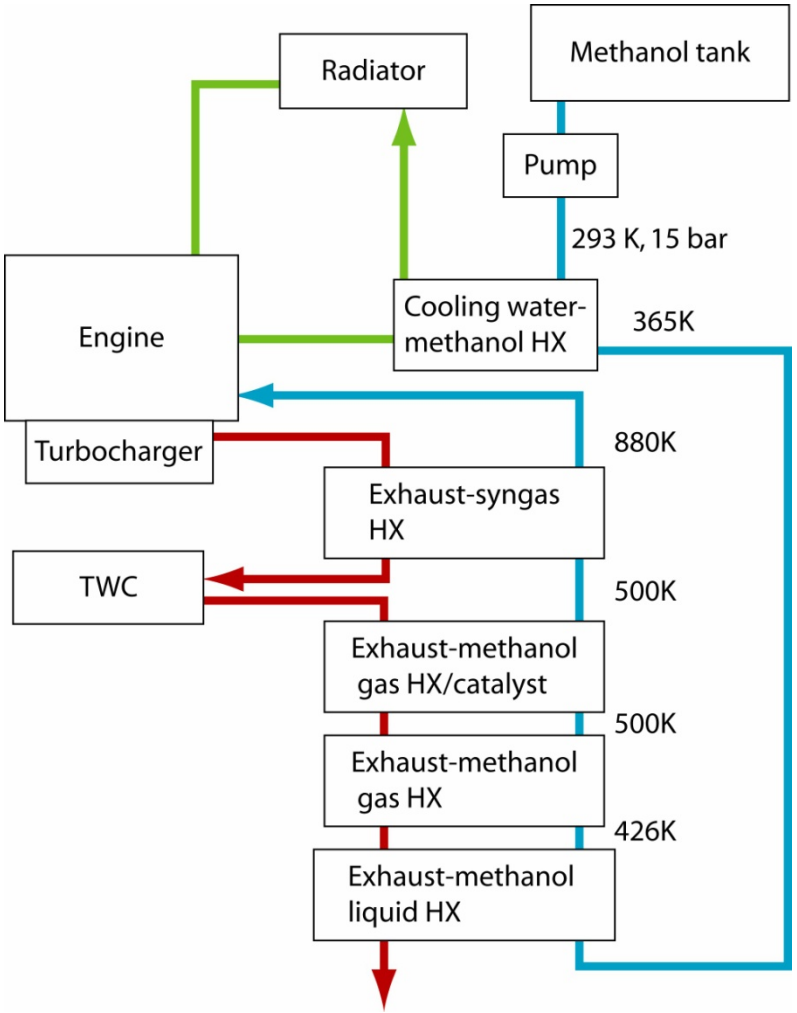
- Methanol Injection can be used to add knock resistance to syngas
- Methanol use minimized in order to reform as much methanol as possible
- Increased knock resistance from vaporization cooling
  - Direct Injection
  - “Open-valve” port fuel injection (removes need for adding additional penetration in modified engine)

Open Rankine Cycle

- Rankine cycle uses heat to convert pressurized liquid into hot gas that does mechanical work
- In Open Rankine cycle gas is introduced into engine rather than being condensed into liquid
- Gas has energy from both chemical conversion of methanol to syn gas and increased heat energy
- Hot gas is used to do mechanical work and also provides fuel with increased chemical energy to engine

Methanol Open Rankine Cycle With Engine Energy Recovery

- Heat Exchanger system transfers exhaust heat to methanol and syngas
- Produces syngas with higher chemical energy and higher temperature
- Syn gas is introduced into engine so as to do mechanical work on piston and is then combusted
- “Open” Rankine cycle: working fluid is introduced into engine rather than being recycled.

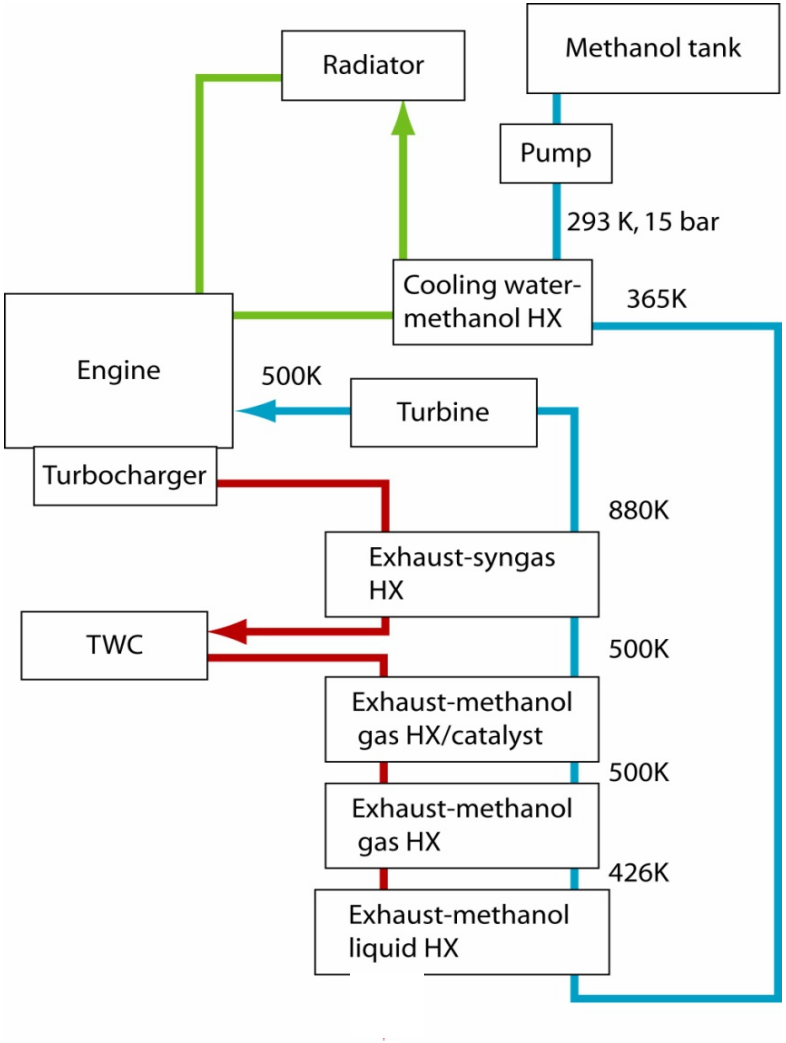


Heat Recovery By Mechanical Work in Engine

- Inject hot H2-rich gas during compression stroke prior to sparking

- Injection through valve that is separate from air in take valve

Methanol Open Rankine Cycle With Turbine Energy Recovery



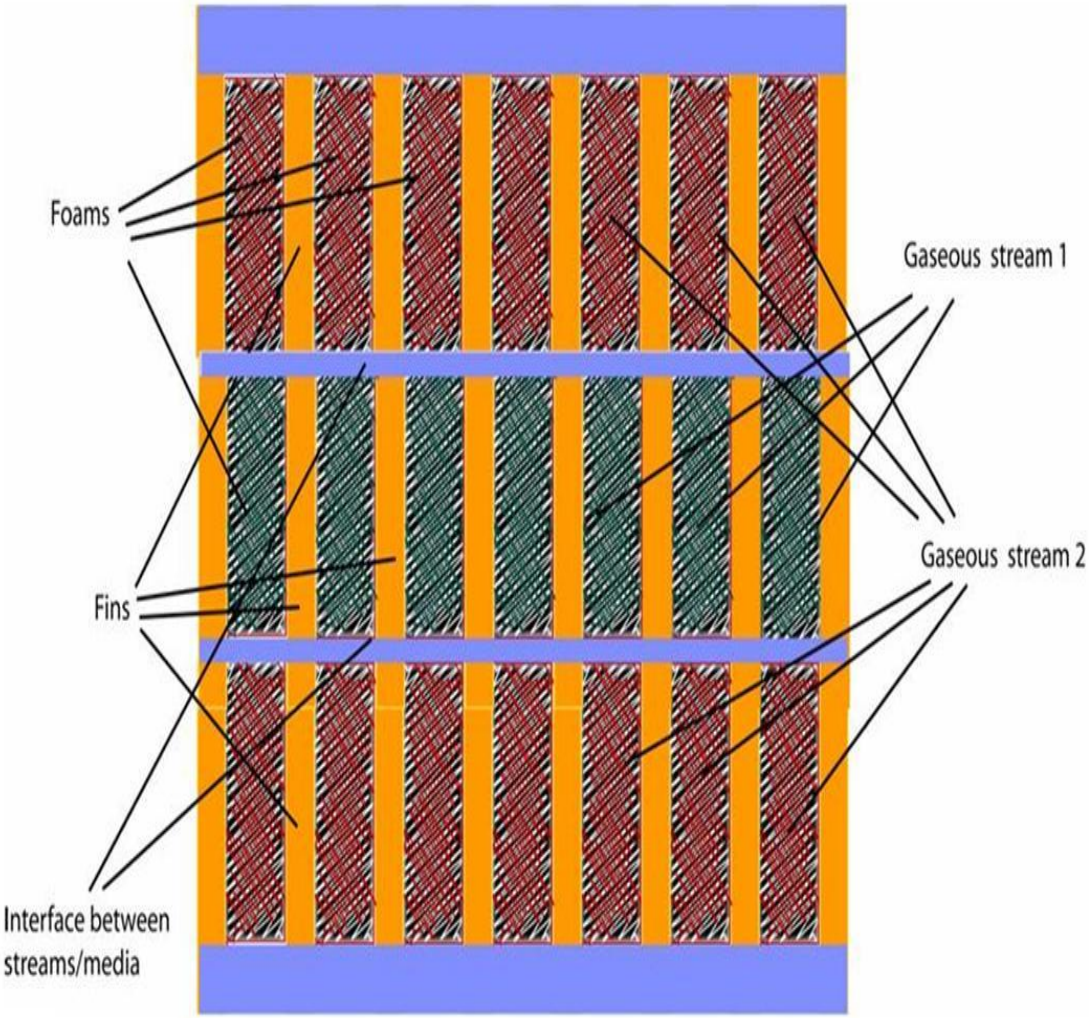
Metallic Foam Heat Exchanger

- New compact heat exchanger increases reformer effectiveness
- Use of metallic foams improves exhaust heat transfer to gas
  - great thermal contact with gas (lots of surface area)
- However, because of very high porosity, foams have poor thermal conductivity
- This drawback is removed by combining foam with fins that have high thermal conductivity

porous metal foams

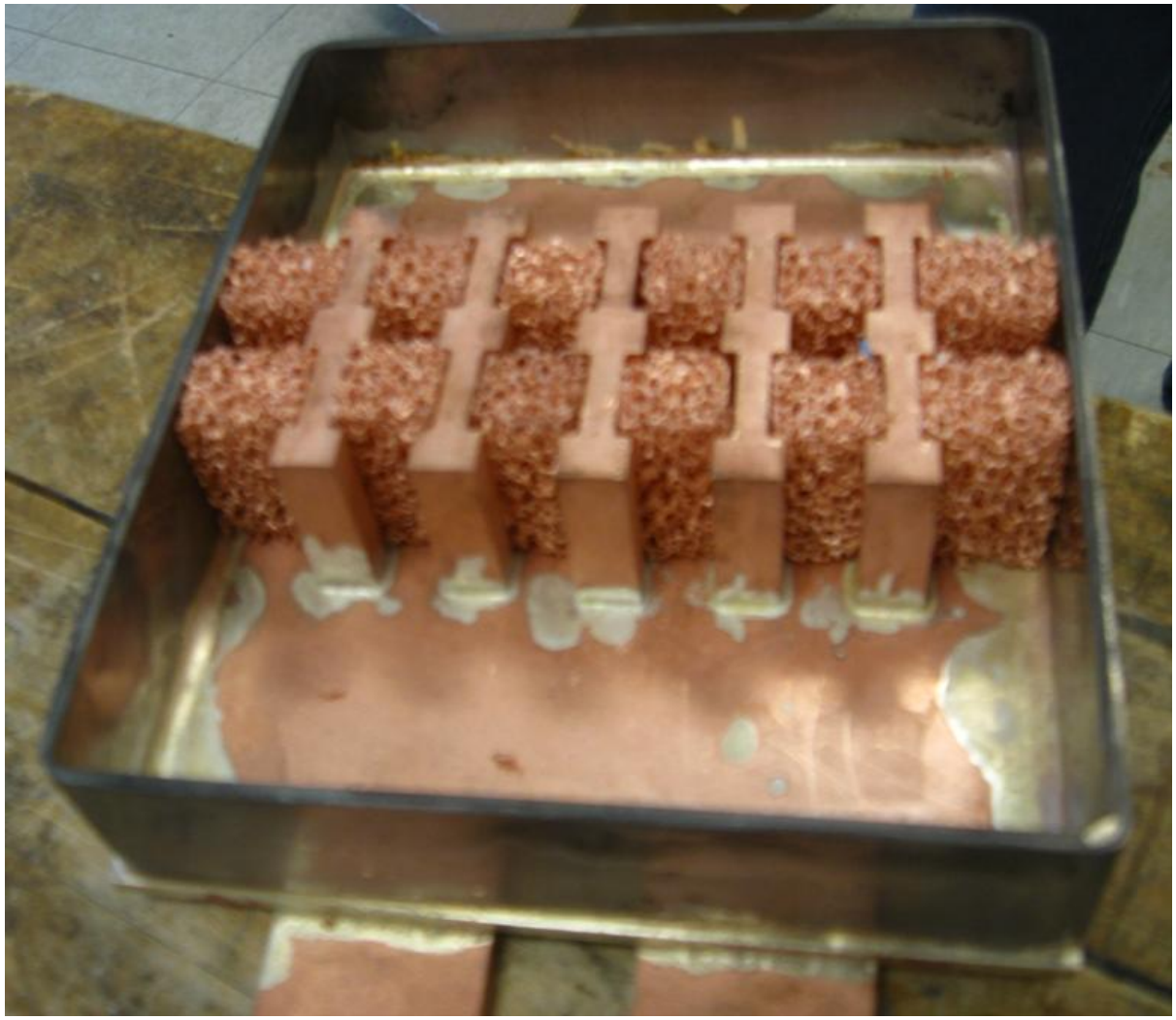
" Foam on Fins" Heat exchanger For Exhaust Heat Recovery

- Need efficient, compact heat exchanger design for vehicular applications
- Foam metals are very attractive
  - High surface heat transfer coefficient,
  - However, have low thermal conductivity
  - Solution: Foam on fins



Cryogenic heat exchanger

current lead for superconducting applications



Potential Reformer Exhaust Energy Recovery with Other Engines

- Diesel pilot ignited Otto cycle engine with lean operation
- Diesel- methanol dual -fuel Compression Ignition Engine
- Premixed Compression Ignition Engines
- Tradeoffs need to be assessed

Potential Use of Open Methanol Rankine Cycle in Gas Turbine

- Methanol under pressure is reformed into syngas which has more chemical energy than methanol
- Syngas also has elevated temperature that is provided by heat exchange with turbine coolant and exhaust gas
- Syngas powers first turbine and is then combusted in burner to power second turbine
- Potential efficiency increase of 25 %

Summary

- Evolutionary use of spark ignition type methanol engine can provide
  -Near term use of well established engine technology with very low emissions and with option for operation entirely on diesel fuel
  - Longer term use of highly effective exhaust heat recovery

- Methanol offers potential for very effective waste heat recovery
  - Recover heat from engine exhaust (major) and coolant (minor)
  - Potential engine efficiency ~ 55-60%
    (considerably exceeds diesel efficiency and can rival fuel cell)
  - Could significantly increase attractiveness of using methanol for ship propulsion