

차세대 연료 및 에너지 재생 연구실 소개

Introduction to Advanced Fuel and Regenerated Energy Laboratory

오세철

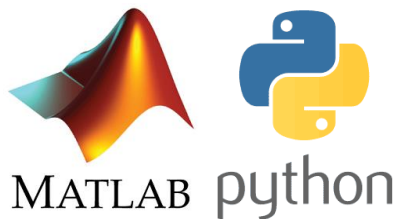
연구실 소개



Advanced Fuel and Regenerated Energy Lab.

차세대 연료 및 에너지 재생 연구실

1. 선박 및 차량용 파워트레인 시스템의 차세대 연료 기반 연소 및 배출가스 저감 기술
2. 촉매 기반 연료 개질 및 기초 연소 특성 연구 – 발전용 암모니아 연료전지 시스템 적용 대상
3. 전과정분석 (Life Cycle Assessment, LCA) 기반 E-fuel 및 청정 수소 생산 기술



Cantera 기반 시뮬레이션 + lab-scale 실험



이화여자대학교
EWHA WOMANS UNIVERSITY



세종대학교
SEJONG UNIVERSITY



한국기계연구원
KOREA INSTITUTE OF MACHINERY & MATERIALS



한국에너지기술연구원
KOREA INSTITUTE OF ENERGY RESEARCH



HYUNDAI
MOBIS

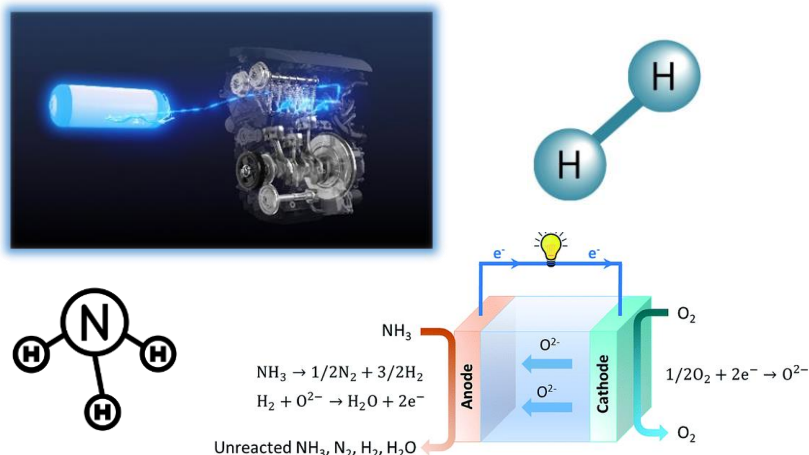


이노베이션

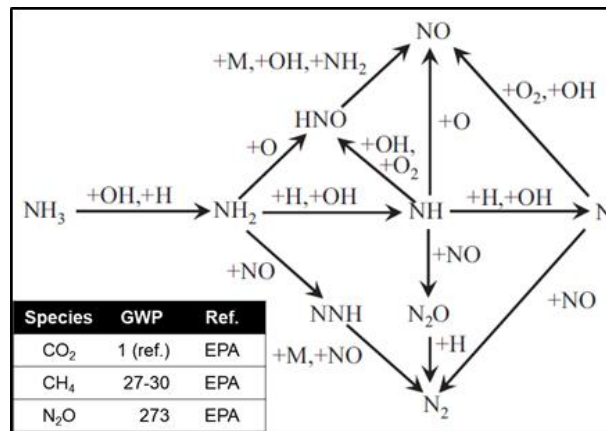


다양한 기관과의 협업 진행 예정

1. Clean fuel-based energy conversion – combustion and electrochemical basis

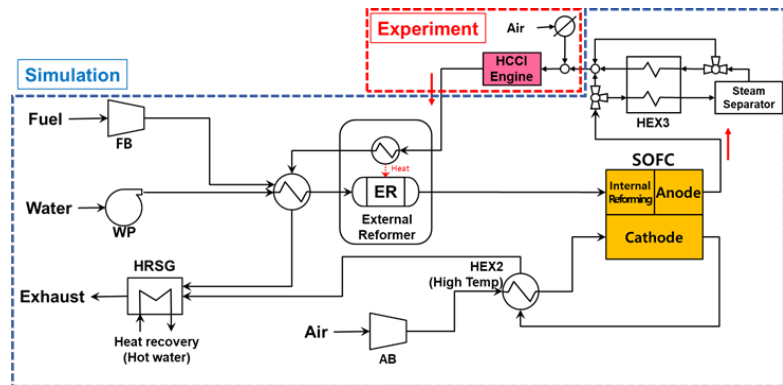


Clean fuel-based energy conversion devices



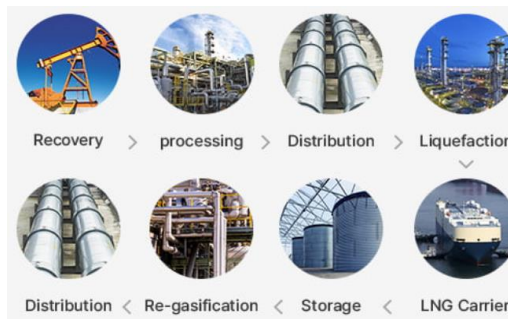
Reducing emissions from energy conversion

2. Thermodynamic system modeling and analysis (HILS)



Fuel cell distributed power generation system – 0D modeling with exp. data

3. Life Cycle Analysis for various fuels and powertrains

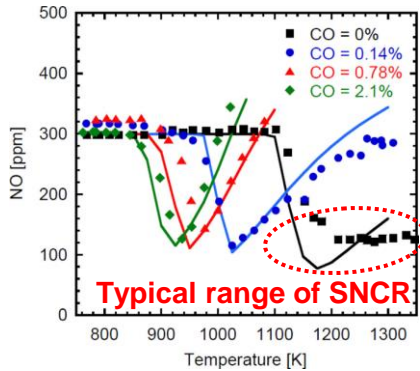


H₂ and NH₃ Life Cycle Assessment

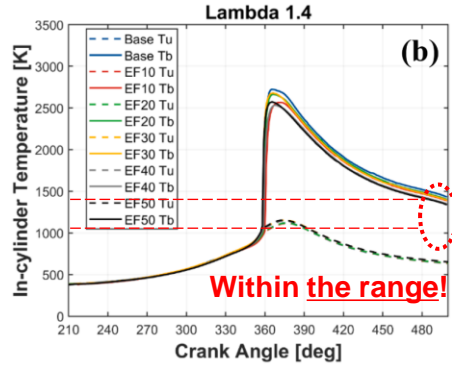


Recycling wasted battery

■ 선박용 암모니아-천연가스 엔진 SNCR 시뮬레이션



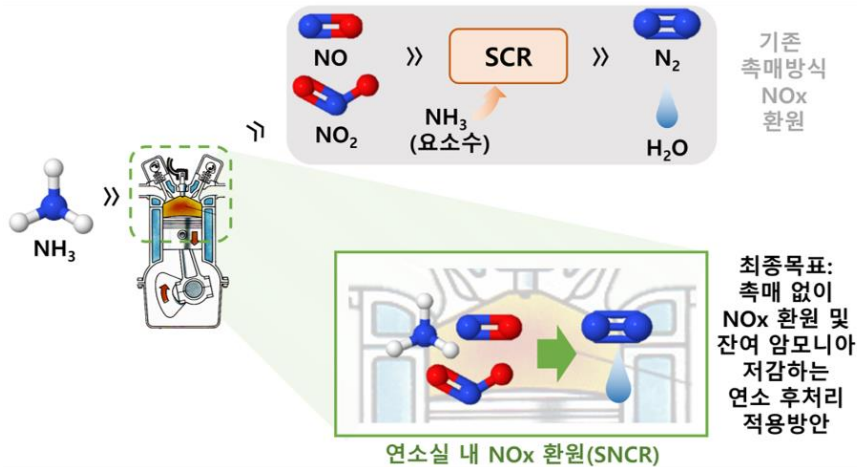
Examples of SNCR with CO existence



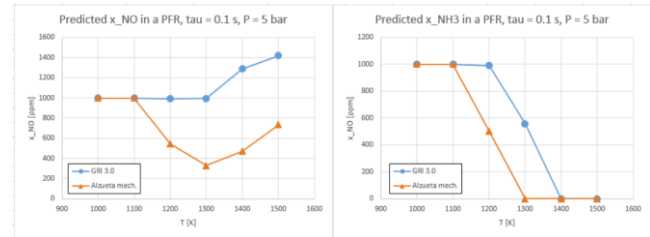
In-cylinder temperature profile from engine exp.

- Cantera 기반 천연가스-암모니아 선박 엔진 연소 – 배기 행정 모사 시뮬레이션
- 촉매 없는 환경에서의 NOx 환원 (암모니아에 의한) 가능성 및 배출가스 동시 저감 가능성 검증

Methodology – 1st step (modeling and sim.)



1. Find the proper mechanism that explains exp. results.

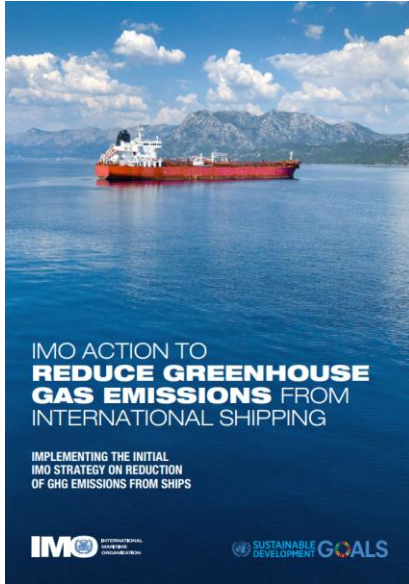


0D simulation results (GRI 3.0 mech. vs. Alzueta's mech.)

2. Develop 0D model of powertrain. (engine / gas turbine / etc.)
3. Find the condition that ammonia can be exhausted **intentionally** and SNCR occurs.

인턴십 주제 1-1

■ 선박용 암모니아-천연가스 엔진 SNCR 시뮬레이션

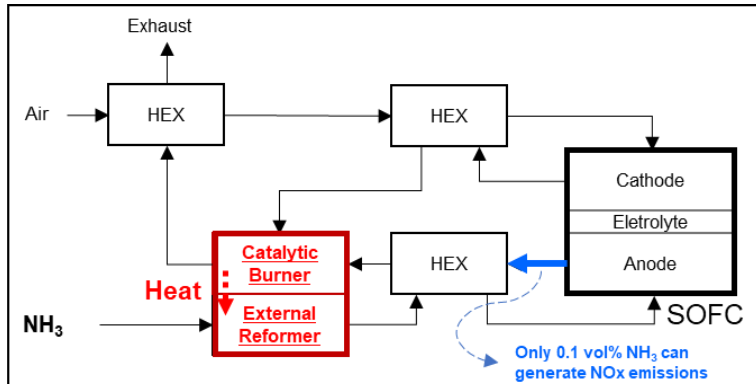


.1	<p>carbon intensity of the ship to decline through implementation of further phases of the energy efficiency design index (EEDI) for new ships</p> <p>to review with the aim to strengthen the energy efficiency design requirements for ships with the percentage improvement for each phase to be determined for each ship type, as appropriate;</p>
.2	<p>carbon intensity of international shipping to decline</p> <p>to reduce CO₂ emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008; and</p>
.3	<p>GHG emissions from international shipping to peak and decline</p> <p>to peak GHG emissions from international shipping as soon as possible and to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008 whilst pursuing efforts towards phasing them out as called for in the Vision as a point on a pathway of CO₂ emissions reduction consistent with the Paris Agreement temperature goals.</p>

.1	<p>carbon intensity of the ship to decline through further improvement of the energy efficiency for new ships</p> <p>to review with the aim of strengthening the energy efficiency design requirements for ships;</p>
.2	<p>carbon intensity of international shipping to decline</p> <p>to reduce CO₂ emissions per transport work, as an average across international shipping, by at least 40% by 2030, compared to 2008;</p>
.3	<p>uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources to increase</p> <p>uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources to represent at least 5%, striving for 10%, of the energy used by international shipping by 2030; and</p>
.4	<p>GHG emissions from international shipping to reach net zero</p> <p>to peak GHG emissions from international shipping as soon as possible and to reach net-zero GHG emissions by or around, i.e. close to, 2050, taking into account different national circumstances, whilst pursuing efforts towards phasing them out as called for in the Vision consistent with the long-term temperature goal set out in Article 2 of the Paris Agreement.</p>

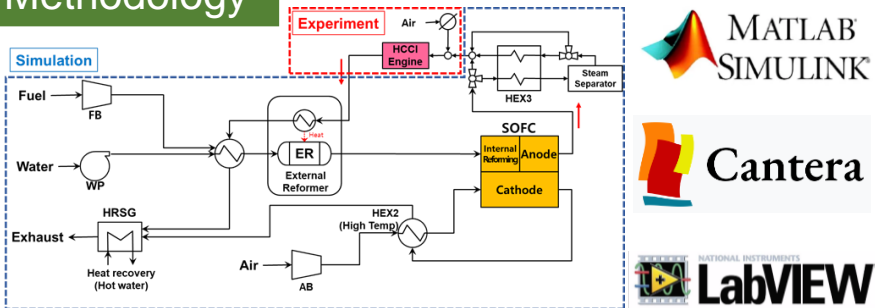
- 선박 추진 엔진 기술 현황 조사 + IMO 배기규제 관련 문헌 조사 및 정리
- 미분탄-암모니아 혼소 (새로운 화력발전) 및 발전소별 전략 관련 문헌 조사 및 정리
- 질소산화물 저감 기술과 관련된 리뷰 논문 제시 (교수자) → 학습 및 요약 (학생)
- (선택) Cantera toolbox 학습 – MATLAB, Python 중 1개 이상 선택
- (선택) 암모니아-천연가스 혼소 엔진 실험 데이터 모사 시뮬레이션 진행

■ 암모니아 SOFC 연료전지 시스템 모델링 – 촉매연소 실험 결과 적용 (HILS)



- Cantera 기반 암모니아 SOFC 연료전지 시스템 0D 모델링
- 암모니아 산화 촉매 NOx 측정 실험 결과 기반 시스템 운전점 예측 시뮬레이션

Methodology



Configuration of fuel cell system modeling (example from former study)

- System **0D modeling** (SOFC, BoP, heat exchanger, etc.) via **Cantera** toolbox and MATLAB software
- Adopting experimental data with Labview-based DAQ

System analysis

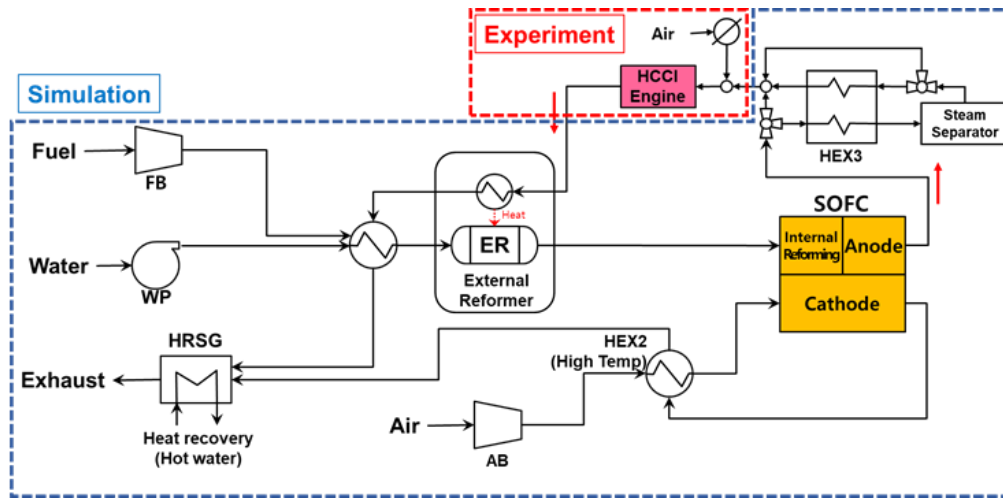


Flow reactor experiment setup for decomposition and oxidation of ammonia

- Customizing catalyst-support materials and test
 - ➔ Reforming ratio (i.e. duty) and decomposition T
 - ➔ NOx selectivity, especially N₂O pathway

Catalytic oxidation and reforming exp. (main BoP)

- 암모니아 SOFC 연료전지 시스템 모델링 – 촉매연소 실험 결과 적용 (HILS)



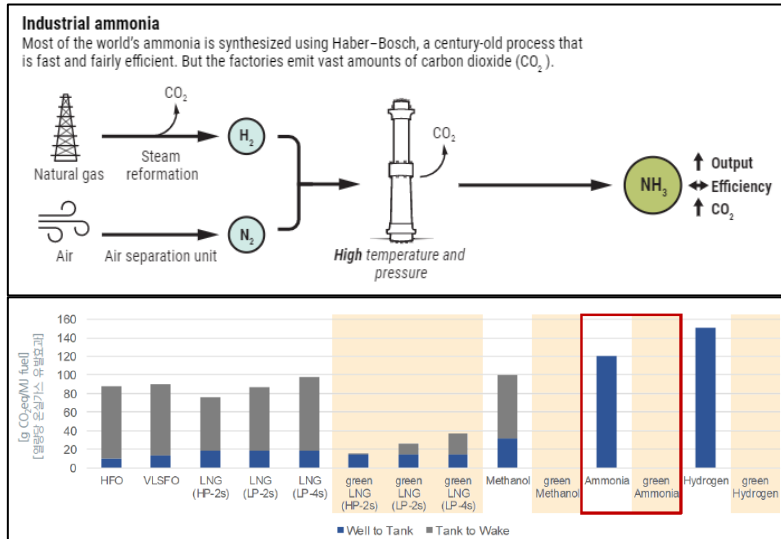
AMOGY



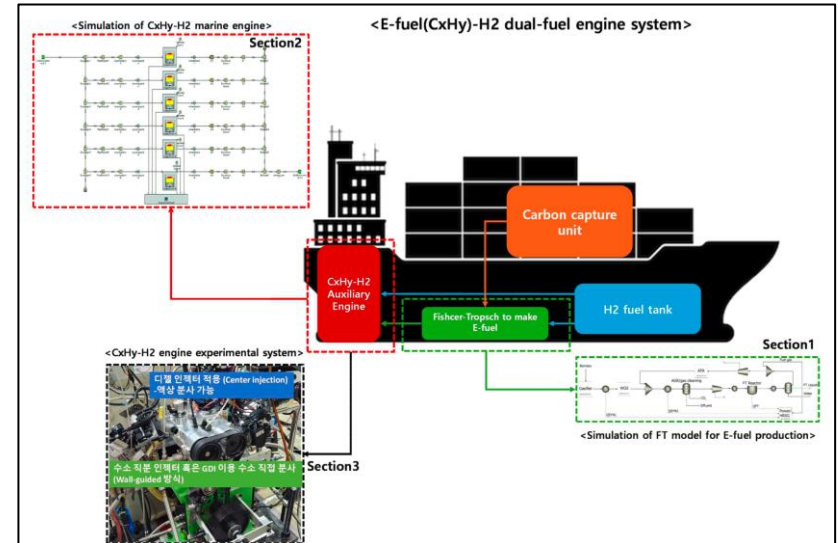
- 암모니아 연료전지 관련 기술 동향 조사 – AMOGY (벤처 기업), KIST, KIER 및 KIMM
- 배출가스 후처리, 연료 개질 등에 사용되는 촉매 종류 조사 (귀금속, 비귀금속)
- 암모니아 연료전지 및 촉매 연소 관련 리뷰 논문 제시 (교수자) → 학습 및 요약 (학생)
- (선택) Cantera toolbox 학습 – MATLAB, Python 중 1개 이상 선택
- (선택) 암모니아 연료전지 시스템 0D 모델링

인턴십 주제 3-1

- 선박 엔진 폐열 회수를 활용한 NH₃ 크래킹 / CO₂ 포집 및 e-fuel 생산 feasibility 분석



Source: KSOE, Kormarine conference 2022



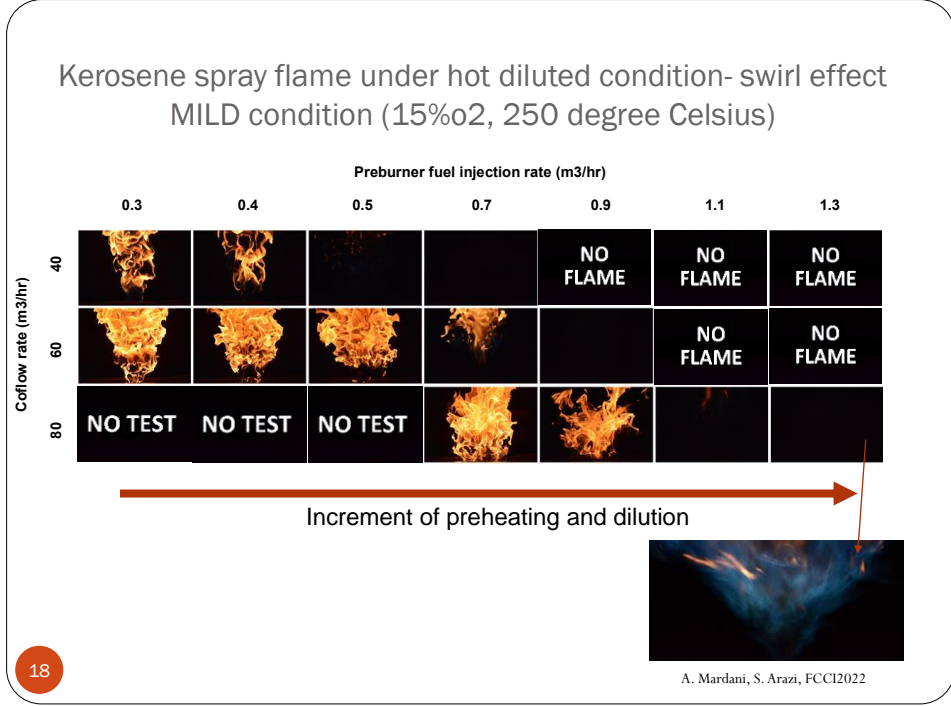
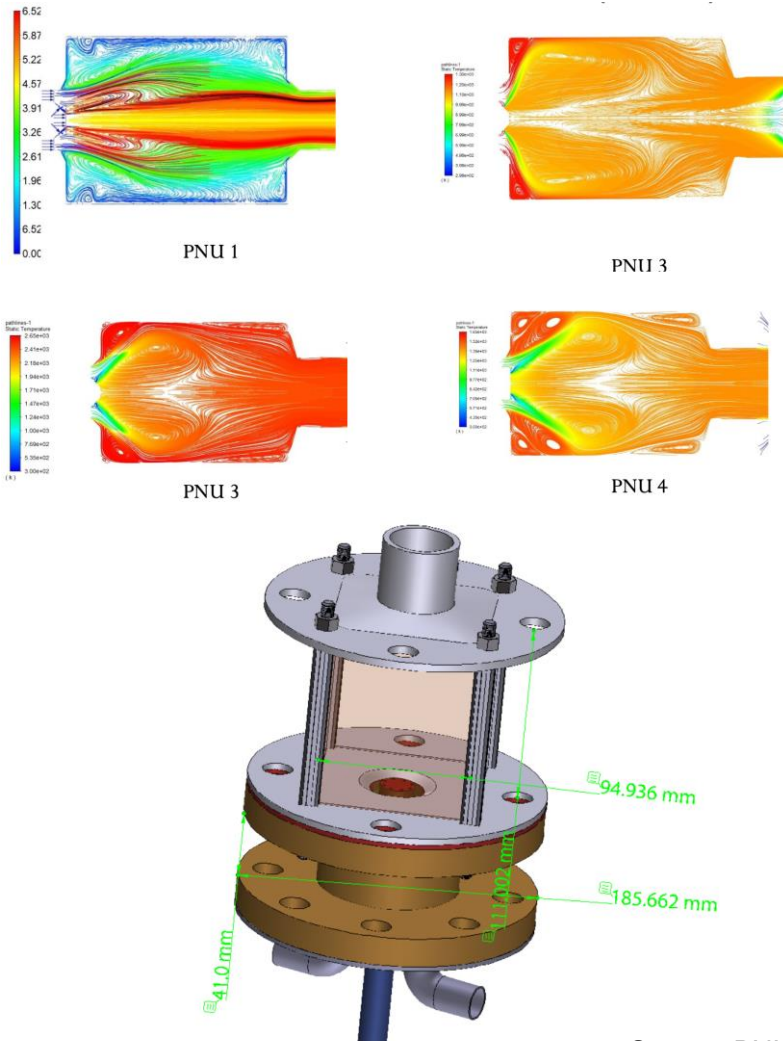
Source: Advenger's Lab, 충남대학교 이정우 교수님 연구실

- 전과정분석 에 대한 개념 학습 및 관련 문헌 조사 & 요약
- E-fuel 의 개념 및 적용 가능 분야 (자동차, 항공, 조선) 의 최신 뉴스 기사 요약
- 그린 수소, 그레이 수소, 블루 수소 등 수소 생산 청정성과 관련된 문헌 요약
- (선택) 선박 추진 시스템의 폐열 회수 환경 모사 및 에너지 재생 가능성 분석
- (선택) 탄소 포집 방식에 따른 선박 e-fuel 생산 및 암모니아 크래킹 feasibility 탐색

심화 주제

인턴십 심화 주제 1-2

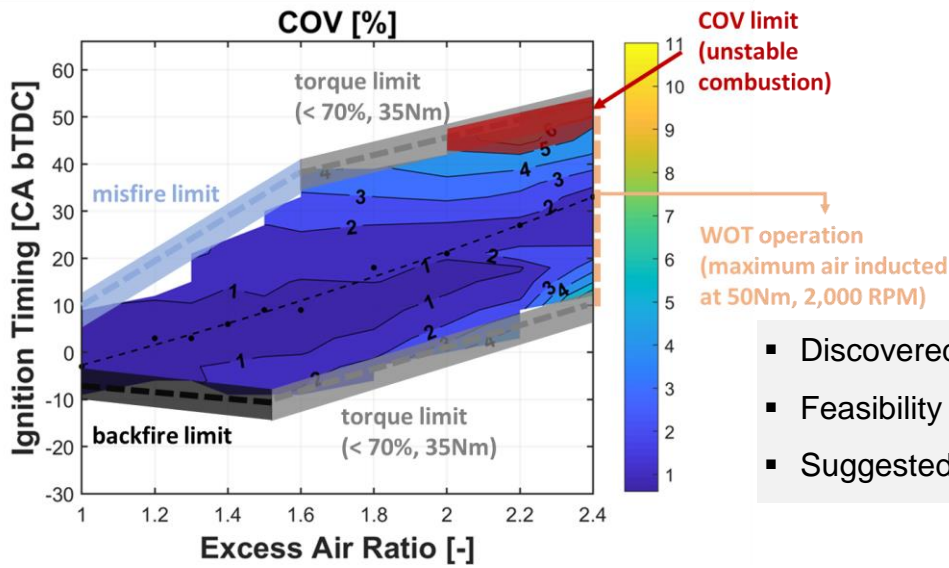
- 암모니아-수소 MILD 연소 기초실험 (부산대학교 친환경스마트선박부품기술혁신센터 연계)



Source: PNU Burner presentation, Prof. Mardani & Professor Emeritus Kyung Chun Kim, 2024

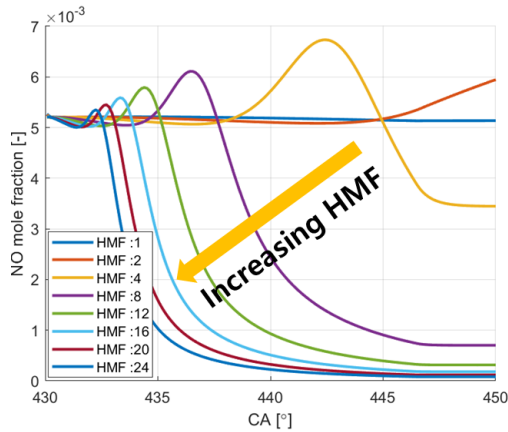
인턴십 심화 주제 1-3

- 차량용 수소 엔진의 질소산화물 저감 기술 개발 (실전문제연구단 진행 중, 서울대-기계연 협업)

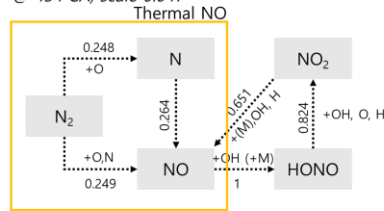


Case #	1	2	3			
Lambda [-]	3.204	2.989	2.808			
RPM [rot/min]	780	799	843			
Brake torque [Nm]	0					
IGN [CA aTDC]	-50	-28	-10			
H ₂ rate [LPM]	15.1	16.5	20			
NOx [ppm] (pre/post)	0.8	0.6	0.57	0.52	0.56	0.69
H ₂ [ppm] (pre/post)	34763	386	34776	479	20417	388

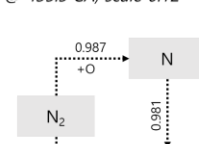
- Discovered the limits of operating point
- Feasibility of using commercial TWC for hydrogen combustion
- Suggested suitable idle operation for hydrogen-fueled engine



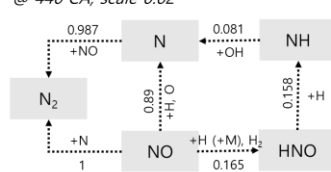
@ 434 CA, scale 0.047



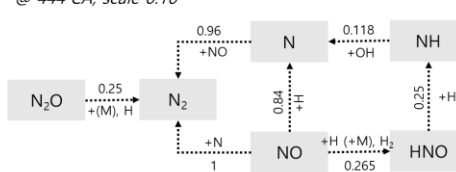
@ 435.5 CA, scale 0.12



@ 440 CA, scale 0.62

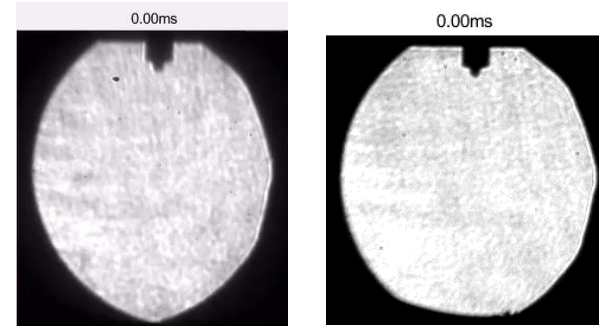
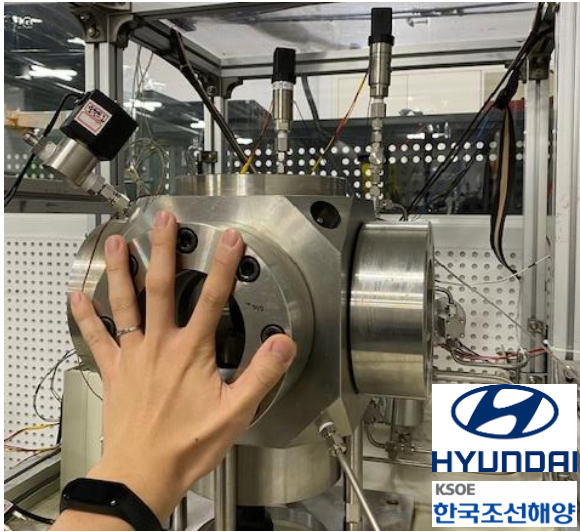


@ 444 CA, scale 0.16

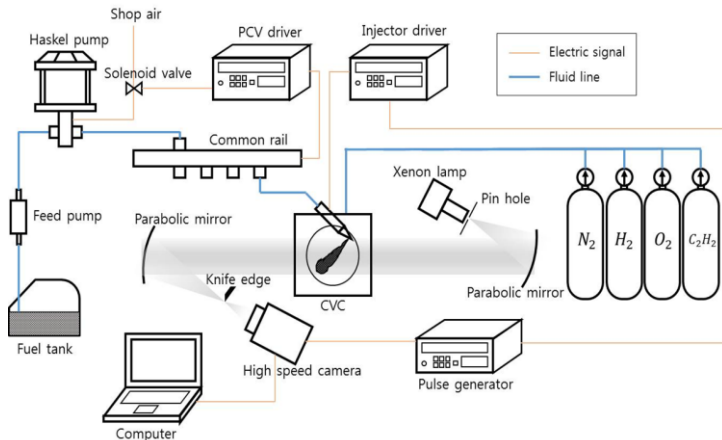


인턴십 심화 주제 1-4

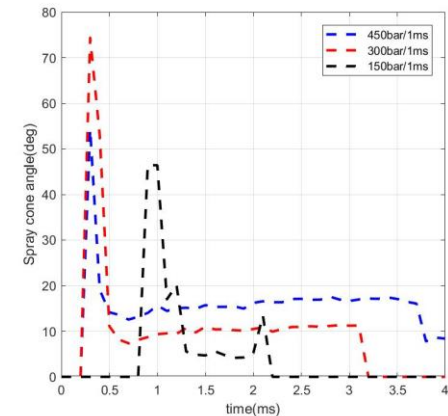
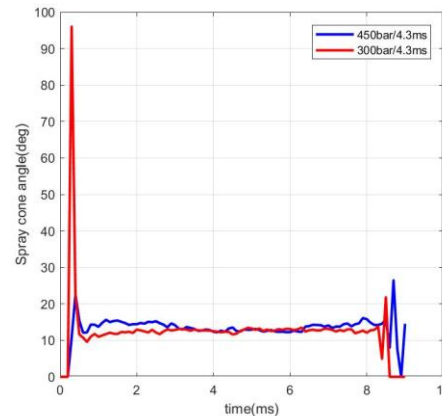
- 암모니아 착화 (diffusion flame ignition) 특성 정적연소실 실험 (서울대 협업)



Constant Volume Chamber – fuel characteristics



Spray cone angle according to injection duration



인턴십 심화 주제 2-2

- 전기화학적 CO₂ 분리 및 압축 기기 시뮬레이션 (KIMM 친환경모빌리티연구실 협업)

작동 mechanism 규명

High pressure Anode AEM Cathode Low pressure

$\text{CO}_2 + \text{H}_2\text{O} + \text{O}_2$ Mechanism? $\text{N}_2 + \text{O}_2 + \text{H}_2\text{O}$

Air + H₂O

- 음이온 교환막을 통한 전기화학적 CO₂ 분리 메커니즘 규명

고효율 막/촉매 스크리닝

Peak power density (mW cm⁻²)

Year

- 막/촉매 종류에 따른 CO₂ 분리 성능 측정
- 효율적인 CO₂ 분리를 위한 전극구조 최적화

전기화학적 CO₂ 분리/압축셀

압축셀 구조 설계

유로형 소결체 다공판

- 효율적인 CO₂ 압축을 위한 가스확산구조 최적화
- CO₂ 고압 압축을 위한 셀 기밀 설계 수행

셀 운전 성능 평가/분석

High pressure Anode AEM Cathode Low pressure

Air + H₂O

$\text{CO}_2 + \text{H}_2\text{O} + \text{O}_2$ $\text{N}_2 + \text{O}_2 + \text{H}_2\text{O}$

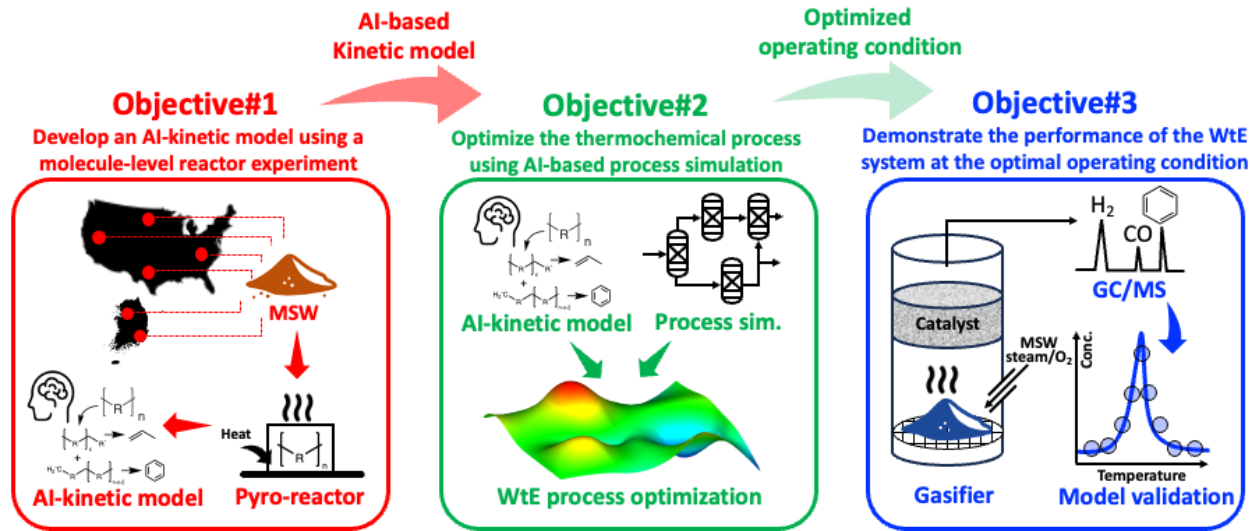
운전 조건: 온도, 습도, 유량

- 유량 및 CO₂농도에 따른 CO₂ 분리/압축 성능 평가
- 효율적인 CO₂ 분리/압축을 위한 최적운전전략 수립

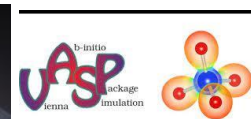
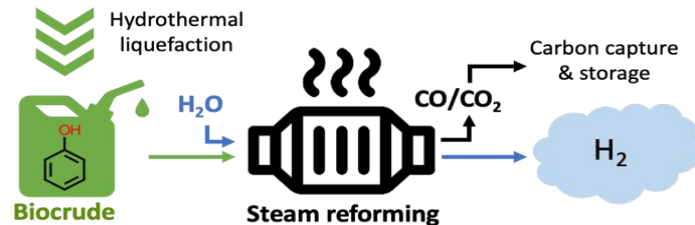
Source: 한국기계연구원 친환경모빌리티연구실, 김선엽 박사님

인턴십 심화 주제 3-2

- MSW (Municipal Solid Waste) 기반 청정 수소 생산 기술 (미국 Texas state Univ. 협업)



Municipal Solid Waste



Prof. Jaeyoung Cho **JTEP**
Univ. of Texas El Paso
(Surface reaction kinetics, DFT)

KETEP 에너지국제공동연구사업
한국에너지기술연구원



Source: Univ. of Texas at El Paso, 조재영 교수님