DENİZCİLİK SEKTÖRÜNDE
KARBONSUZLAŞTIRMA VE ALTERNATİF YAKITLAR

1

Öğr. Gör. Zafer Aydın (Piri Reis Üniversitesi)

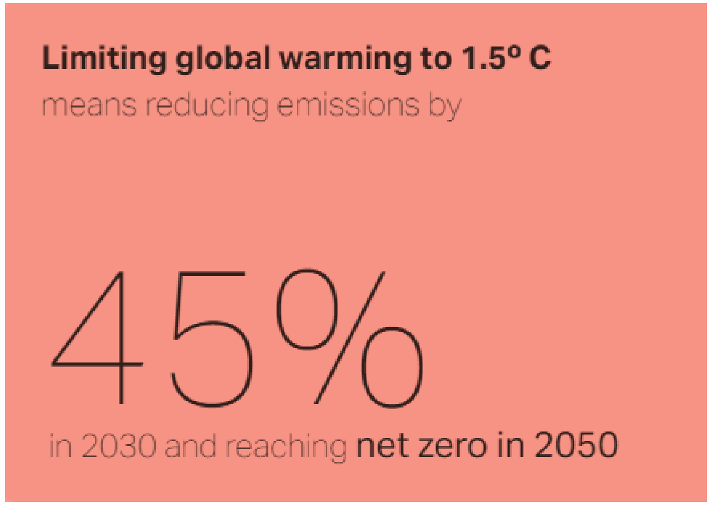
KARBONSUZLAŞTIRMA NEDİR?

2015 yılında Paris'te düzenlenen Birleşmiş Milletler İklim Değişikliği Konferansı, COP21'de 196 taraf ülke, küresel ısınmayı 2°C'nin çok altında sınırlandırarak ve 1,5°C ile sınırlandırma çabalarını ortaya koymuşlardır.

Bu amaçla küresel ısınmanın en büyük nedeni olan Sera gazı etkisini, yani atmosferde biriken karbon içerikli emisyon gazlarının azaltılmasına, yönelik çalışmalar önem kazanmıştır.

Bu hedefe yönelik ifade edilen **Dekarbonizasyon** (Karbonsuzlaştırma) tanımı da temel olarak atmosferde insan kaynaklı oluşan karbon emisyonlarını (Karbondioksit, Karbonmonoksit vs.) azaltma sürecini ifade etmektir.

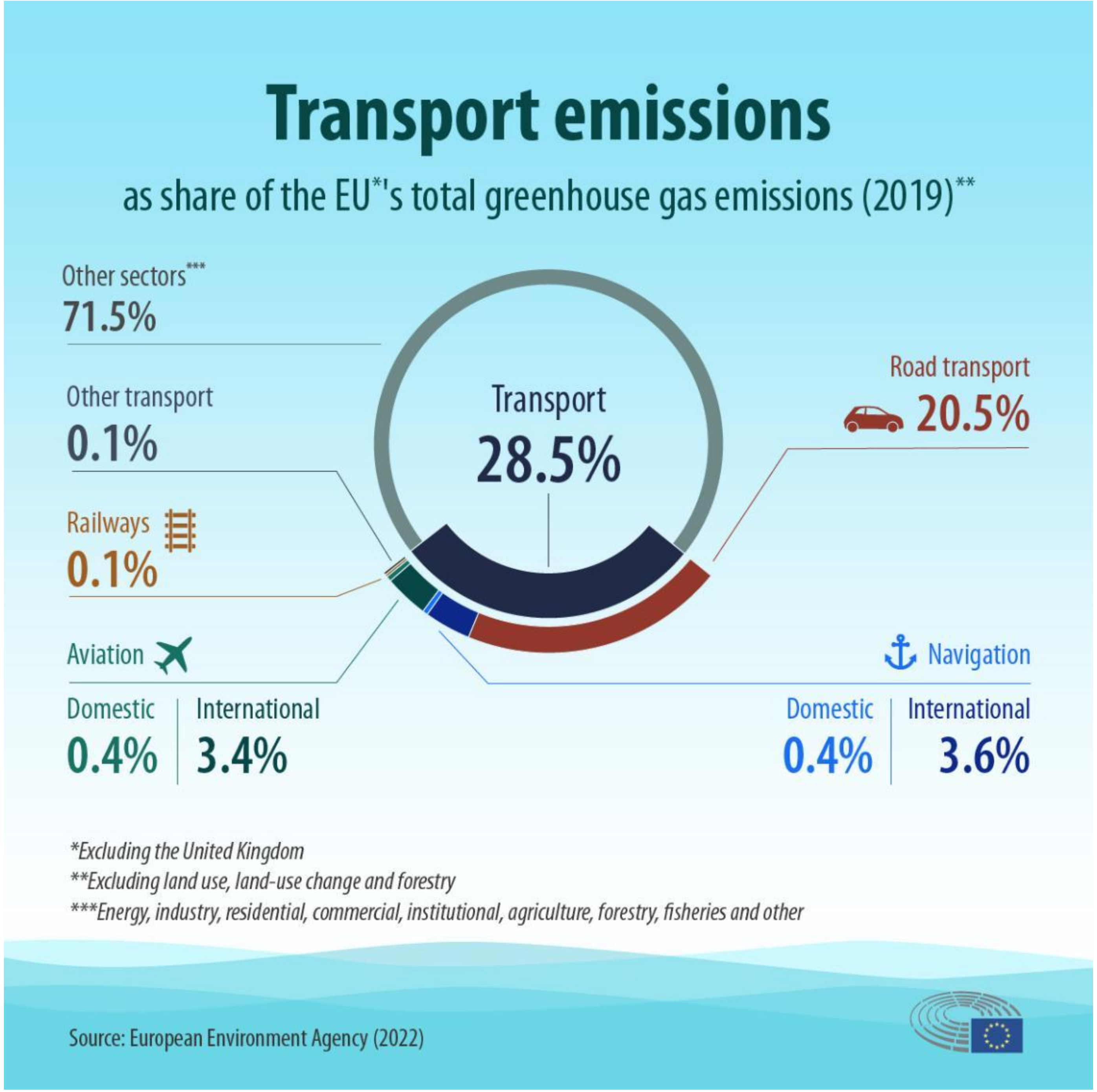
KARBONSUZLAŞTIRMA



Anlaşmanın uygulanmasına yardımcı olmak üzere, iklim değişikliği bilimini değerlendiren BM organı, Hükûmetlerarası İklim Değişikliği Paneli (IPCC) küresel ısınmanın 1.5°C ile nasıl sınırlandırılabileceğine dair bir rapor hazırlamaya davet edildi.

2018 yılında hazırlanan ilk raporda, ilk olarak küresel sera gazı emisyonlarının 2020 ile 2025 yılları arasında zirve yapacağı öngörülmüş olup, aşağıdaki sonuçlar çıkarılmıştır.

- Emisyonlar 2010 seviyelerine kıyasla 2030 yılına kadar %45 oranında azaltılmalıdır ve 2050 yılına kadar net sıfıra ulaşmalıdır.
- Hedef 2050'den sonra da devam etmeli ve tarihi emisyonları telafi etmek için net negatif CO2 seviyelerine ulaşmalıdır.



Küresel ticaretin yaklaşık %80-90'ının deniz taşımacılığı ile gerçekleştirildiği denizcilik sektörü, karbondioksit (CO2) eşdeğeri bazında yıllık küresel sera gazı (GHG) emisyonlarının yaklaşık %3-4'ünden sorumludur.

Tek başına uluslararası deniz taşımacılığı, taşımacılık sektörüyle ilişkili küresel emisyonların yaklaşık %9'unu oluşturmaktadır.

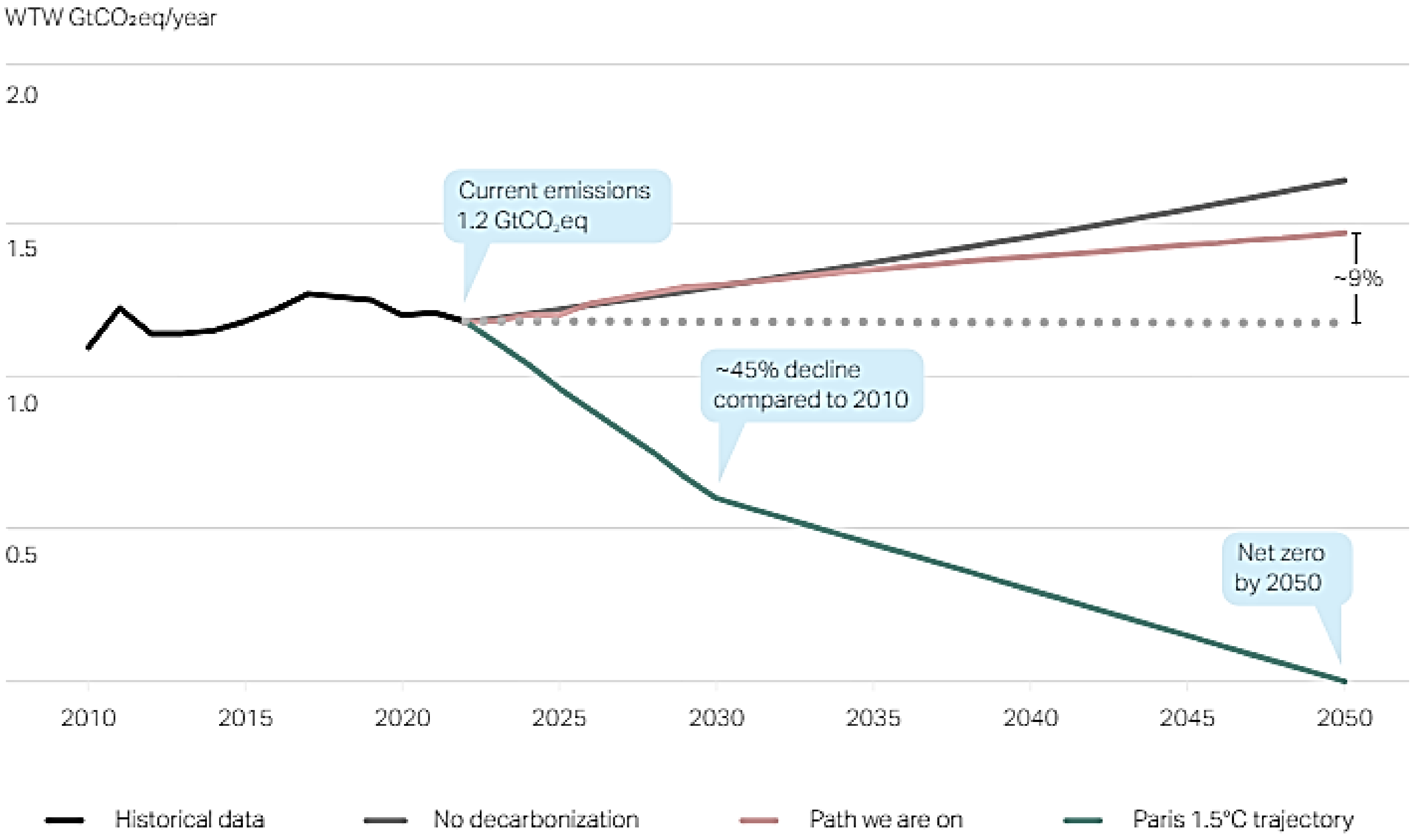
Bunu bir bağlama oturtmak gerekirse, uluslararası denizcilik sektörü bir ülke olsaydı, Almanya ile karşılaştırılabilir CO2 emisyon seviyeleri ile altıncı ila yedinci en büyük CO2 yayıcısı olurdu (Balcombe vd., 2019).

KARBONSUZLAŞTIRMA

IPCC, modellemelerine dayanarak küresel emisyonlarda hızlı bir düşüş ve derin emisyon azaltımları için denizcilik dahil tüm sektörlere çağrıda bulunmuştur.

İçinde bulunduğumuz durumda devam edersek,

- Denizcilik sektörünün önümüzdeki on yıllar boyunca aynı hırs seviyelerini sürdürmesi halinde emisyonların artmaya devam edeceğini göstermektedir.
- Karbonsuzlaştırma çabaları ve stratejileri, münferit gemiler, rotalar veya şirketlerle ilişkili emisyonları azaltacaktır.
- Bununla birlikte, küresel deniz ticaretinin yılda ortalama %1,2 oranında büyüyeceği tahmin edildiğinden, emisyonların 2050 yılında bugüne kıyasla yaklaşık %10 oranında artmasını bekleyebiliriz.



WTW = well-to-wake.
Historical data is based on the Third IMO GHG Study[7] and Fourth IMO GHG Study.[8] 'The path we are on' is based on MMMCZCS data and analysis as described in the ITS 2021.[9]

KARBONSUZLAŞTIRMA

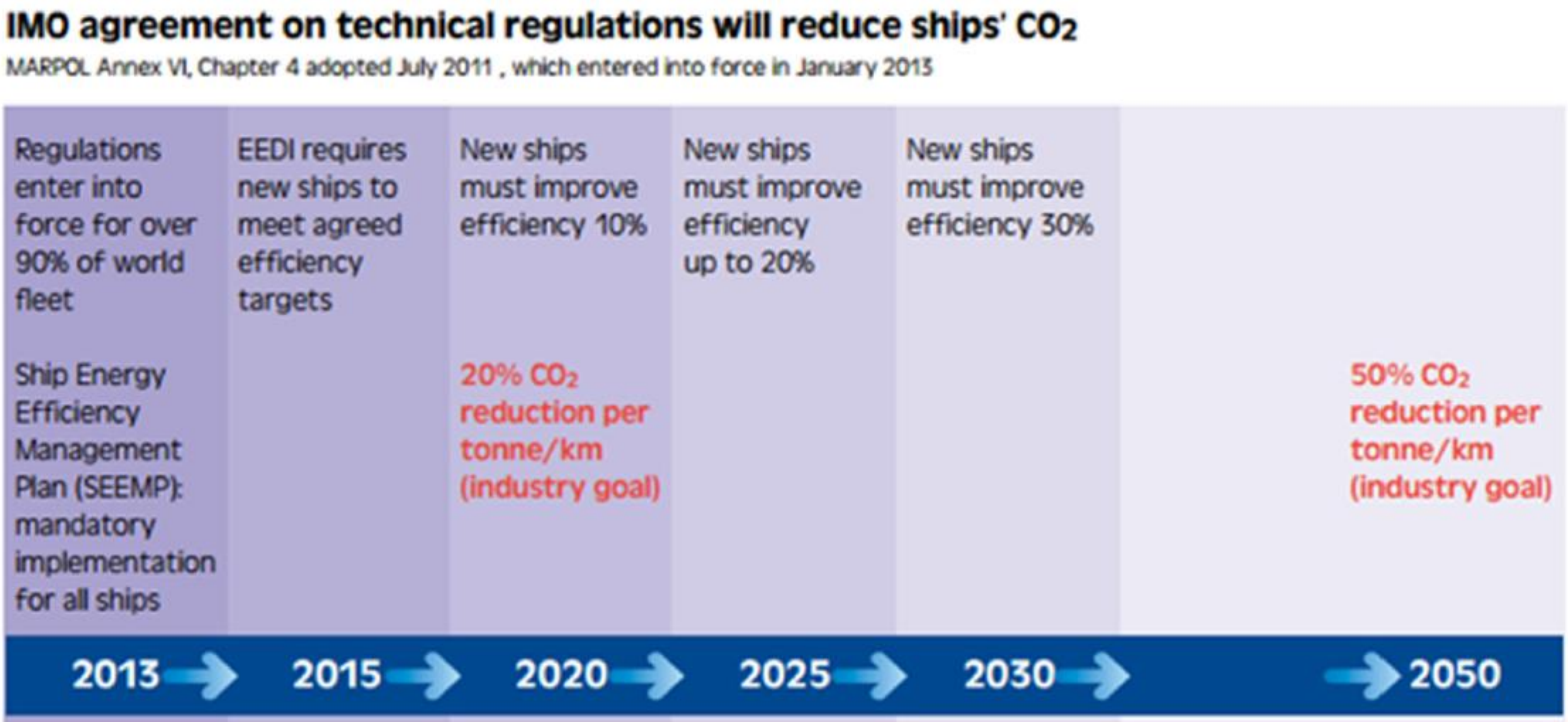
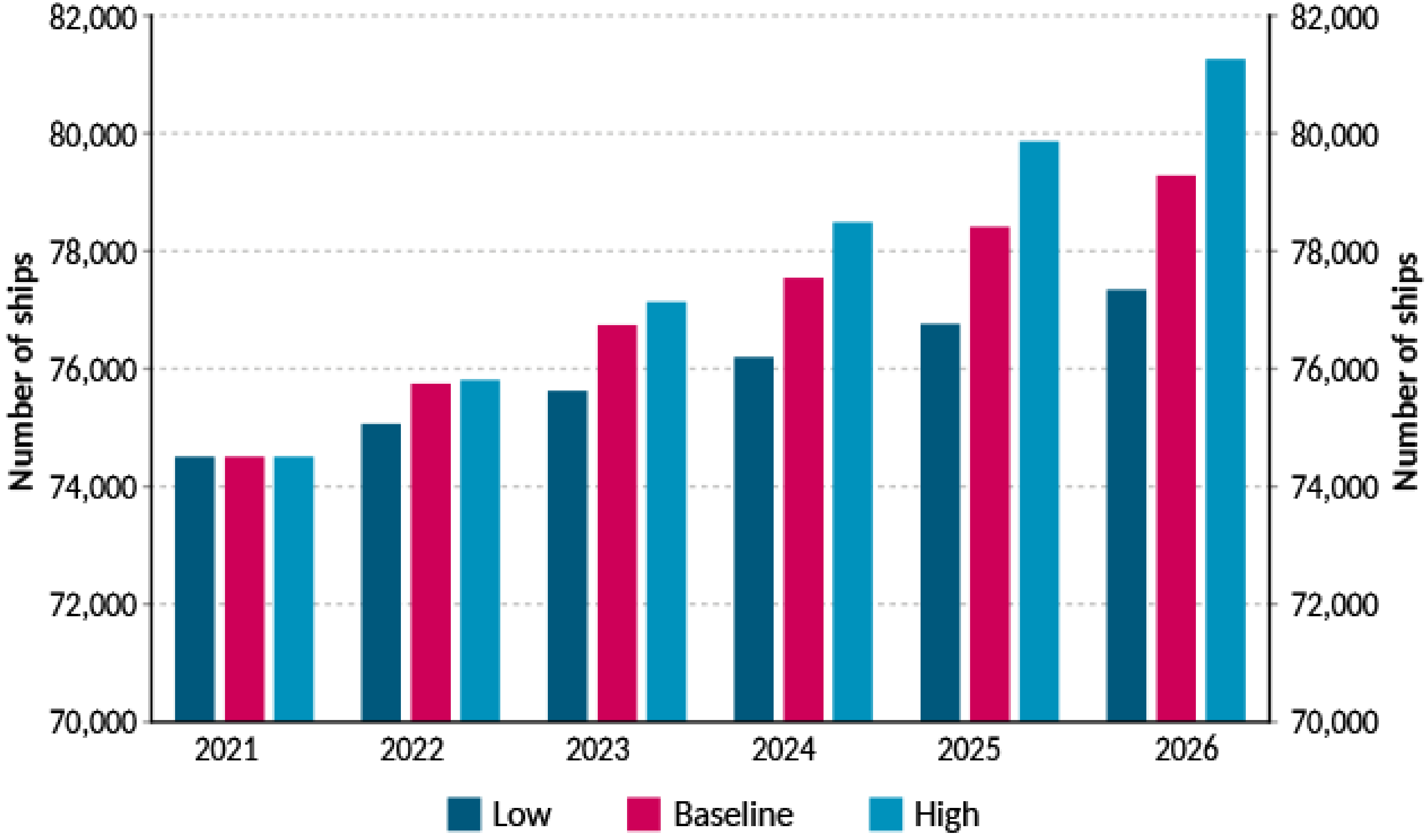


Diagram showing the International Maritime Organization's (IMO) plan for ship improvements from 2013 to 2050

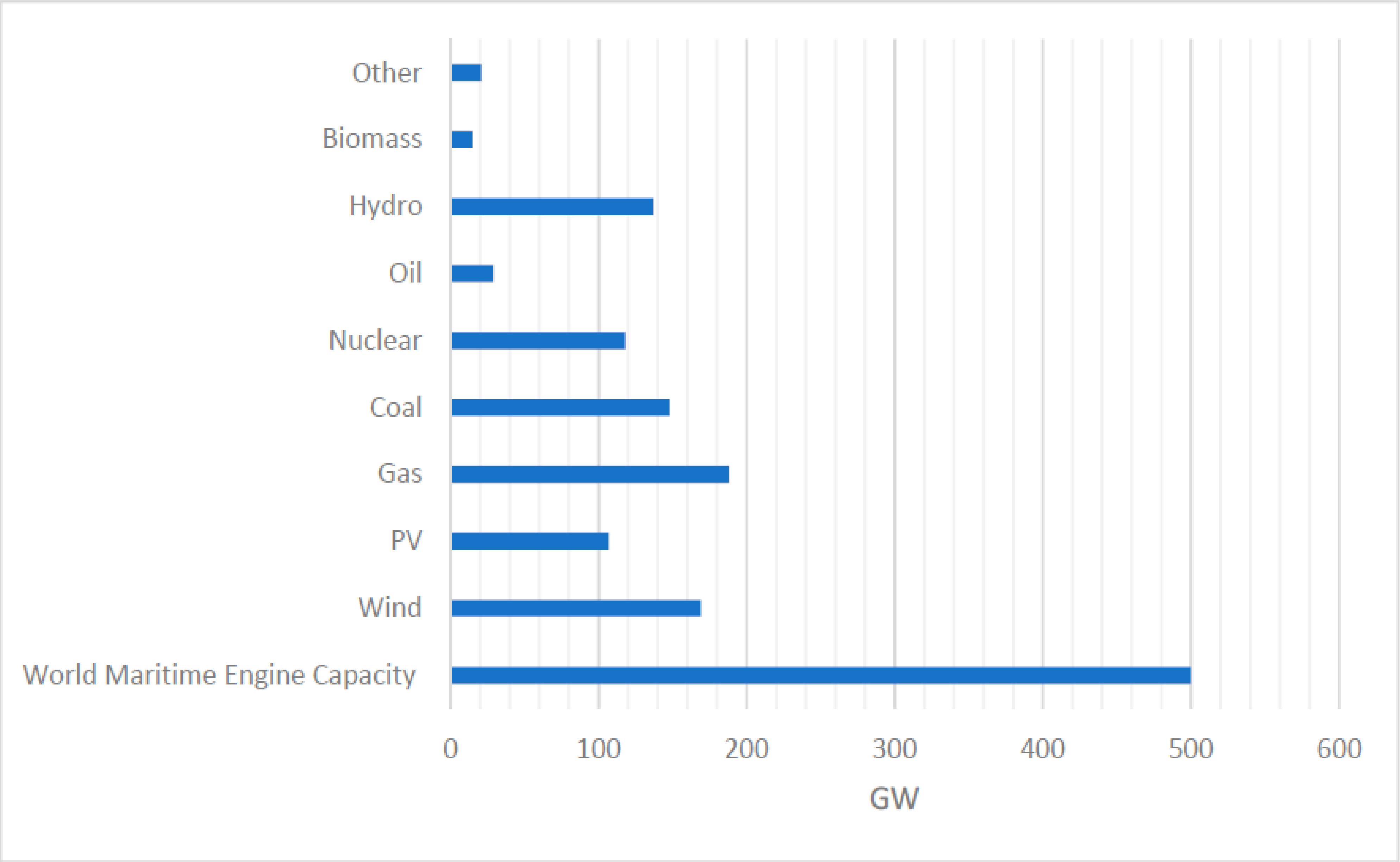
Forecast growth in the world merchant fleet

2021-2026



Source: BIMCO

Note: Number of ships at the start of period specified.
Existing fleet and current orderbook is basis IHS Markit.



Avrupa kurulu gücüne kıyasla dünya denizcilik makine gücü (Grafik, Balcombe et.al (2019) ve Statista'dan alınan verilere dayanarak oluşturulmuştur.)

KARBONSUZLAŞTIRMA

Emisyon indirgeme ve Karbonsuzlaştırma hedefinde yıllardır süre gelen tekniklerin yetersiz kaldığı aşikardır.

Gemiler kaynaklı atmosfere salınan karbonmonoksit (CO), azot oksitler (NOx), kükürt oksitler (SOx) ve partikül madde (PM) emisyonlarına yönelik motorlarda uygulanan iyileştirme teknolojileri devam ederken, karbondioksit (CO_2) salınımının sadece yakıt tüketimini düşürmekle, hatta düşük veya sıfır karbon içeren yakıt kullanmakla mümkün olacağı anlaşılmıştır.

Uluslararası Denizcilik Örgütü'nün (IMO) gemilerden kaynaklanan sera gazı (GHG) emisyonlarının azaltılmasına yönelik ilk stratejisini kabul etmesiyle birlikte, alternatif yakıt ve enerji kaynaklarının kullanımına geçiş, birçok denizcilik şirketi için gerçekçi bir ihtiyaç haline gelmiştir (IMO, 2018).

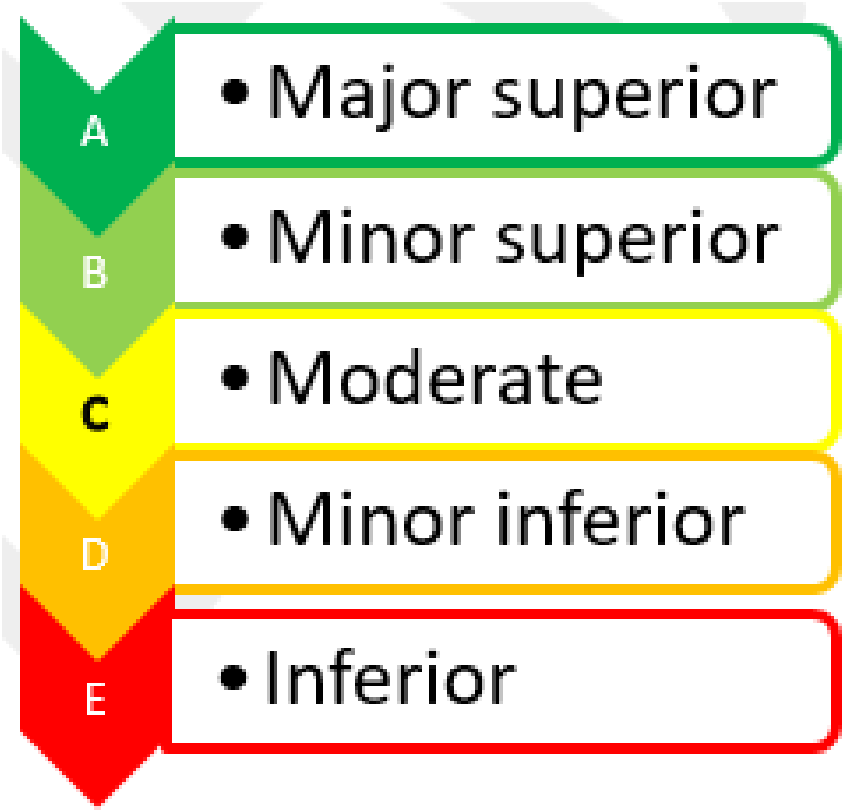
KARBONSUZLAŞTIRMA

Carbon Intensity Indicator (CII)

Karbon Yoğunluğu Göstergesi (CII)

CII, yük taşıma kapasitesi ve deniz mili başına salınan CO2 gramı cinsinden gerçek enerji verimliliğine dayalı olarak bir gemi için derecelendirme sağlar.

Çan eğrisi sistemine benzer bir yöntemle A-E derecelendirmelerini kullanır ve A en iyi enerji verimliliği performansını temsil eder. Derecelendirme eşikleri zaman içinde giderek daha katı hale gelecektir. Eğer bir gemi art arda üç D derecesi veya bir E derecesi alırsa, gemi sahibi bir sonraki takvim yılında uyumluluğa nasıl ulaşacağını gösteren bir düzeltici eylem planı sunmalıdır.

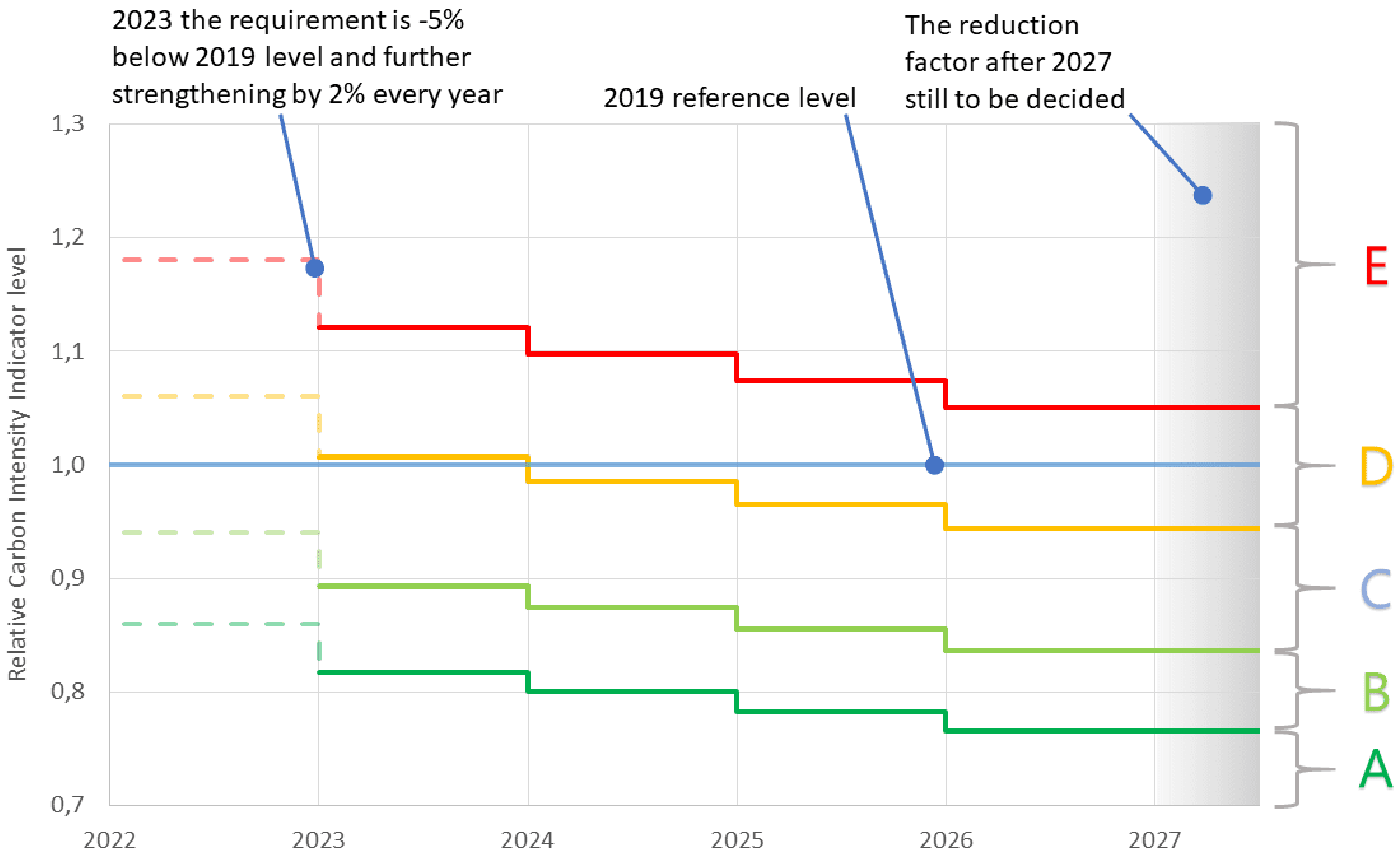


KARBONSUZLAŞTIRMA

$$\text{Attained CII} = \frac{CO_2 \text{ emissions}}{(\text{Deadweight or Gross tonnage}) \times \text{Distance sailed}}$$

Year	Reduction factor (relative to 2019)
2023	5%
2024	7%
2025	9%
2026	11%
2027	TBD
2028	TBD
2029	TBD
2030	TBD

KARBONSUZLAŞTIRMA

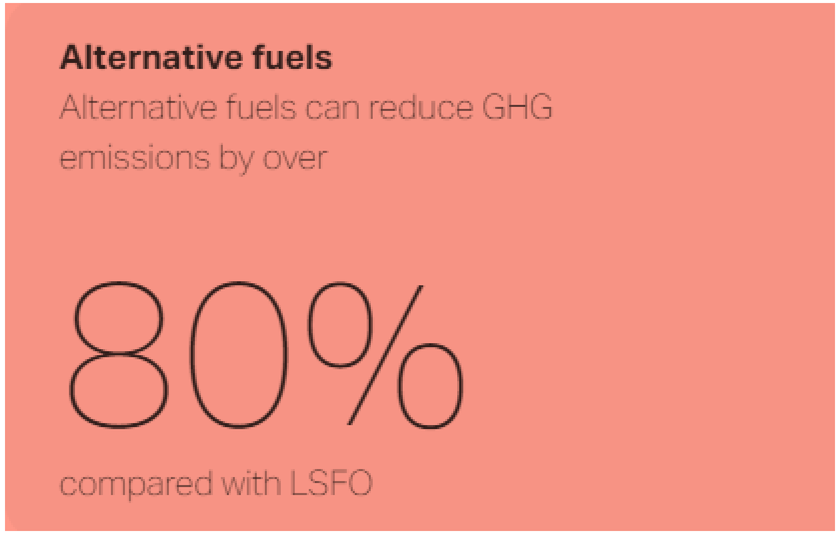


ALTERNATİF YAKITLAR

Günümüzde denizcilik endüstrisi dört ana alternatif yakıt yolunu değerlendirmektedir: metan, metanol, amonyak ve biyodizeller.

Bazıları hidrojeni de alternatif yakıt olarak değerlendirmektedir. Ancak hidrojenin deniz taşımacılığında kullanılmasının önünde düşük hacimsel enerji yoğunluğu, güverte ve kargo alanı üzerindeki etkisi, yüksek basınç ve düşük sıcaklıkta depolama gereklilikleri ve yanıcılık endişeleri gibi çeşitli engeller bulunmaktadır.

Çalışmalar düşük sülfürlü akaryakıttan (LSFO) alternatif yakıtlara geçişin karbon emisyonlarını %80 ila %100 oranında azaltabileceğini göstermektedir.



ALTERNATİF YAKITLAR

Measures	Possible CO_2 Emissions Reductions
Advanced biofuels	25–100%
Liquefied Natural Gas (LNG)	0–20%
Hydrogen	0–100%
Ammonia	0–100%
Fuel cells	2–20%
Electricity	0–100%
Wind	1–32%
Solar	0–12%
Nuclear	0–100%

Alternatif yakıtların kullanımı yoluyla olası CO2 emisyonu azaltımları
(ITF. Decarbonising Maritime Transport. Pathways to Zero-Carbon Shipping by 2035; International Transport Forum: Paris, France, 2018.)

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ALTERNATİF YAKITLAR

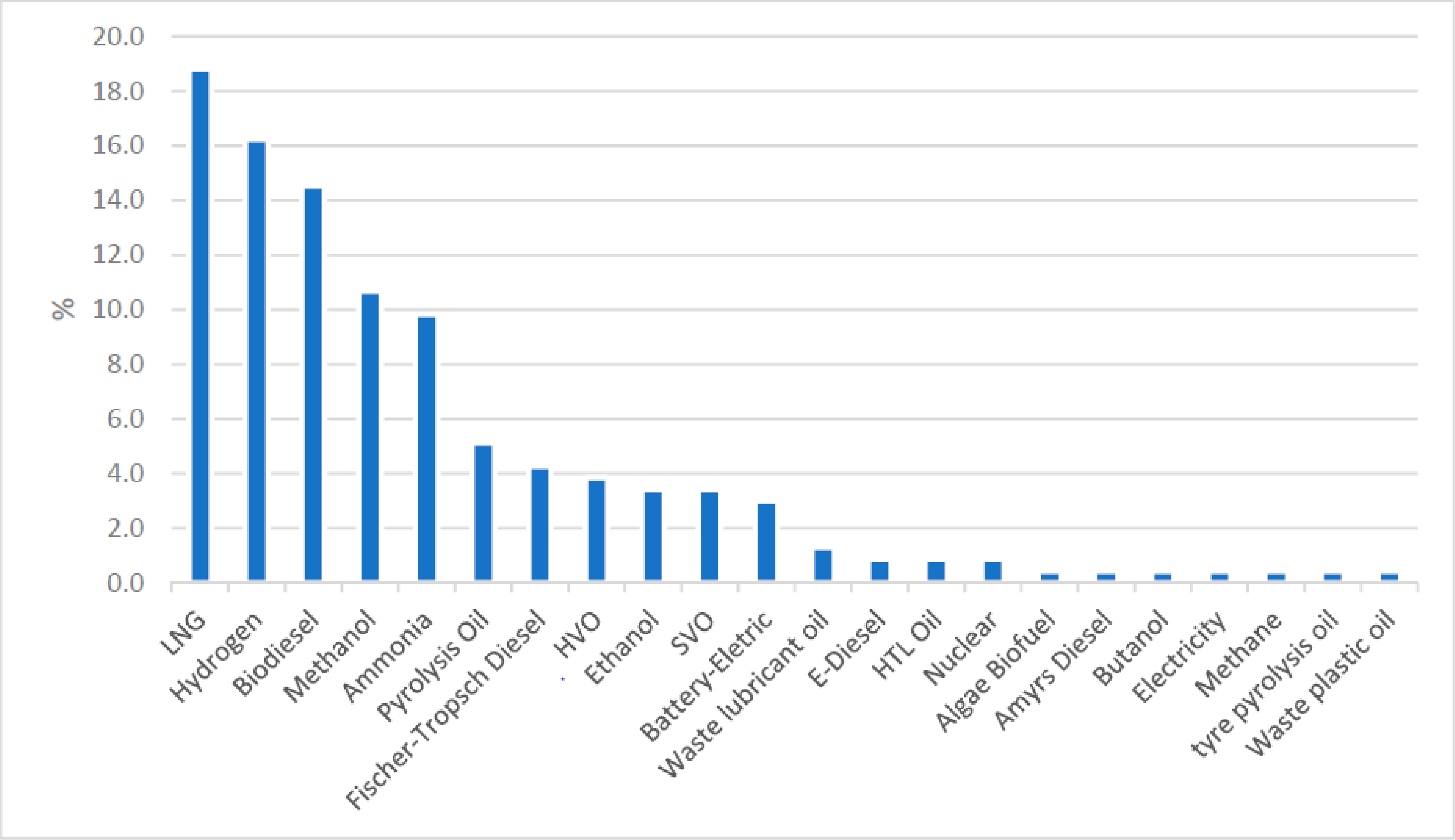


Figure 5. Alternative fuels cited (the figure was constructed based on the selected papers of this present study taken from the web of science database) [30].

ALTERNATİF YAKITLAR

Fuel type	LHV (MJ/kg)	Volumetric energy density (GJ/m³)	Storage pressure (bar)	Storage temperature (°C)
MGO	42.7	36.6	1	120
LNG	50	23.4	1	-162
Methanol	19.9	15.8	1	20
Liquid ammonia	18.6	12.7	1	-34
			8.6	20
Liquid H_2	120	8.5	1	-253
Compressed H_2	120	7.5	700	20

Note: GJ = gigajoules; m^3 = cubic metres.

Source: IRENA (2019a)

ALTERNATİF YAKITLAR

Key fuel properties of alternative marine fuels (DNVGL, 2019b; Xing et al., 2021b).

Fuel	Chemical formula	Density at 15 °C (kgm^{-3})	Cetane number	Boiling point °C	Auto-ignition temperature in air °C	Flammability limits in air vol%	Toxicity	CO_2[a]	SO_x[a]	NO_x[a]	PM[a]
LSHFO	C_8–C_{25}	975–1010	>20	>180	230	0.6–7.5	–	High	Medium	High	Medium
MDO	C_{10}–C_{15}	796–841	>35	>180	210	0.6–7.5	–	High	Low	High	Low
NG	CH_4	0.78	130[b]	−162	540	5.0–15.0	NT	Medium	Low	Medium	Low
METH	CH_3OH	792	<5	65	464	6.7–36	LAT	Medium	Low	Medium	Low
HYD	H_2	0.09	>130[b]	−253	585	4.0–75.0	NT	Low	Low	High	Low
AMMO	NH_3	0.73	120[b]	−33	651	15.0–28.0	HT	Low	Low	High	Low
HVO	C_{15}–C_{18}	770–790	>70	>180	204	0.6–7.5	NT	High	Low	High	Low
ELEC	N/A	N/A	N/A	N/A	N/A	N/A	–	–	–	–	–

Note-.

[a] Combustion emissions in ICE; LSHFO: low sulfur HFO; MDO: marine diesel oil; NG: natural gas; METH: methanol; HYD: hydrogen; HVO: Hydrotreated vegetable oil (advanced biodiesel); AMMO: ammonia; ELEC; electricity; N/A: not applicable; NT: Not toxic; LAT: Low acute toxicity; HT: Highly toxic.

[b] Octane number.

ALTERNATİF YAKITLAR

Status of viability for different alternative fuels (DNVGL, 2019a, b).

Criteria	LNG	Methanol	HVO	Ammonia[c]	Hydrogen[c]	Fully electric[c]
Energy density	4	4	5	3	2	1
Technological maturity	4	3	5	2	2	3
Local emissions	4	4	2	3	5	5
GHG emissions	2[b]	2[b]	4	5	5	5
Energy cost	5	3	2	1	1	V[d]
Capital cost	4	4	5	4	1	5
Converter storage	3	4	5	4	1	1
Bunkering availability	4	3	1	2	1	2
Commercial readiness[a]	5	4	3	2	1	V
Flammability	5	4	5	2	1	5
Toxicity	5	3	5	1	5	5
Regulations and guidelines	5	4	5	3	1	4
Global production capacity and locations	5	3	2	3	3	1

1-5: status rating with 1 being extremely poor and 5 being excellent.

V: varies.

e. Needs to be evaluated case-by-case. Not applicable for deep-sea shipping.

[a] Taking into account maturity and availability of technology and fuel.

[b] GHG benefits for LNG and methanol will proportionally increase with the fraction of corresponding bio- or synthetic energy carrier used as drop-in fuel.

[c] Only from renewable energy sources.

[d] Large regional variations.

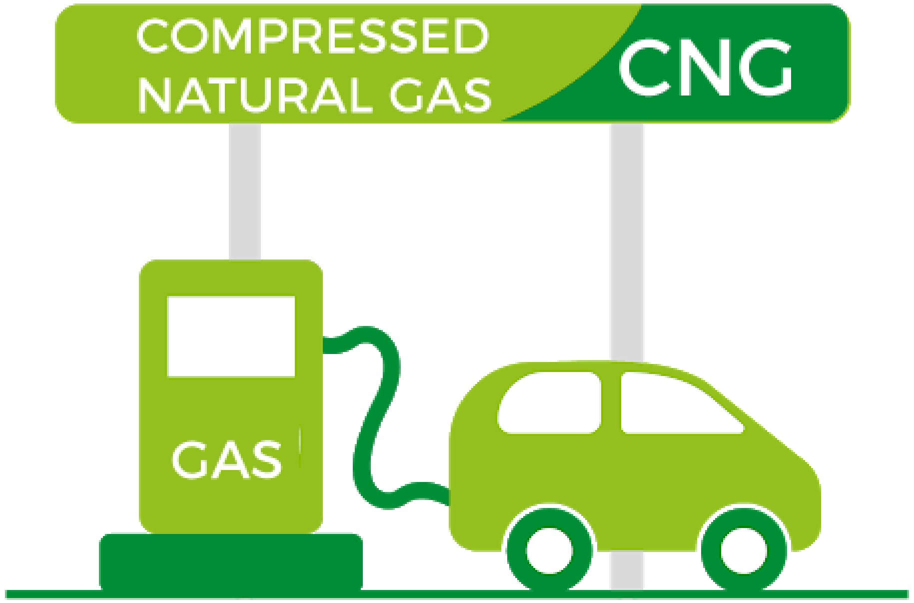
DOĞALGAZ

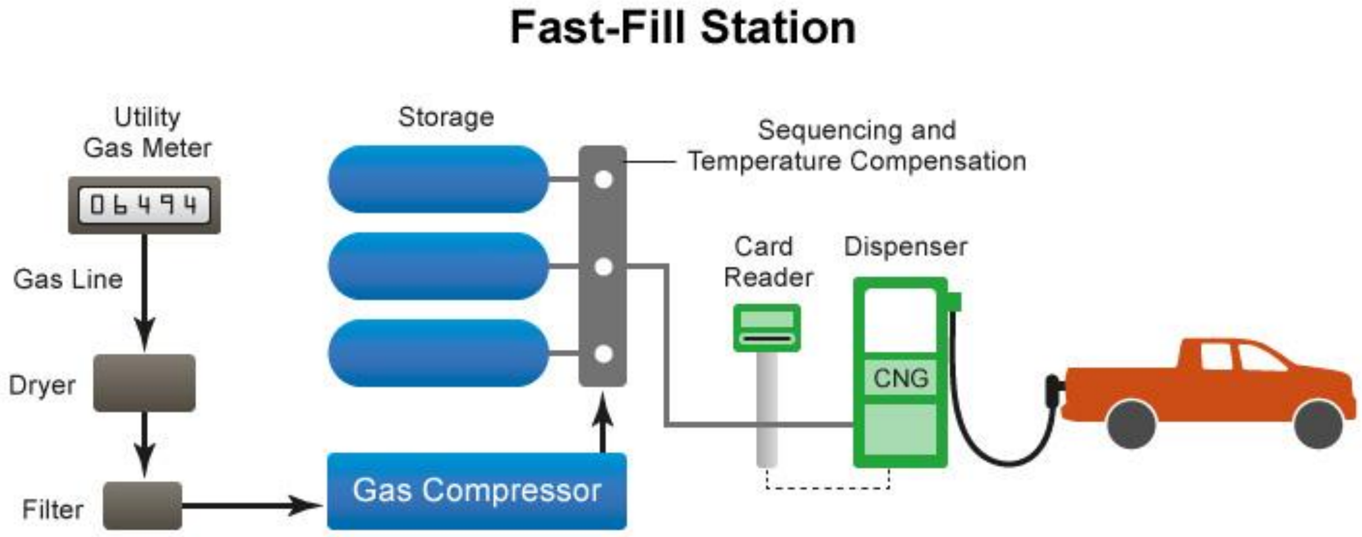
DOĞALGAZ – CH_4

CO_2 emisyonlarıyla mücadele iklim üzerindeki etkilerin sınırlandırılması açısından kilit önem taşısa da, IPCC metan gibi diğer sera gazlarının etkilerine de dikkat çekmiştir

Metan, 100 yıl içinde CO_2'den 28 kat daha yüksek bir küresel ısınma potansiyeline sahiptir.

Tahminler, metan emisyonlarının sanayi öncesi dönemden bu yana yaklaşık 0.5°C ısınmaya neden olduğunu göstermektedir.





DOĞALGAZ – CH_4

Doğalgaz, karbondioksit emisyonlarını gerçekten azaltsa da, karbon bazlı bir yakıt olduğu için karbondioksit yaymaya devam eder (Balcombe vd., 2022) ve bir çözüm olmanın aksine yalnızca bir azaltım seçeneği olarak kullanılabilir (Bouman vd., 2017; Hwang vd., 2020).

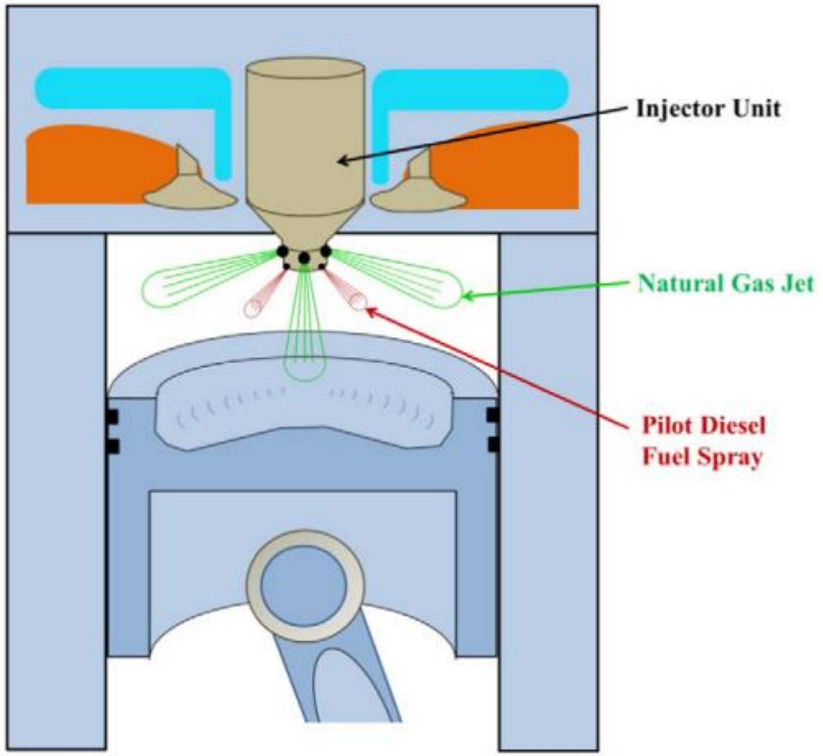


Fig. 2. The schematic diagram of high pressure direct injection system.

DOĞALGAZ – CH_4

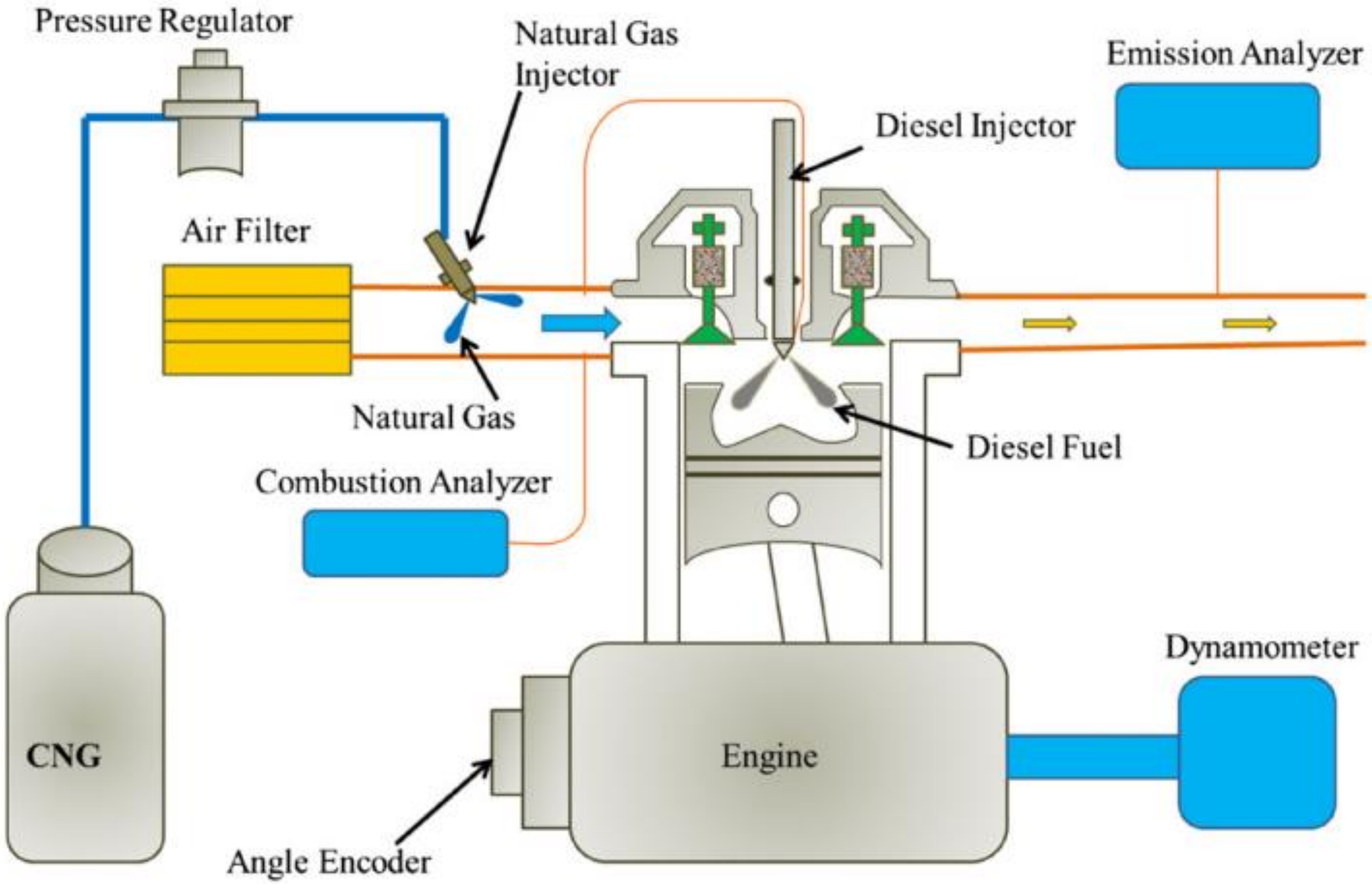
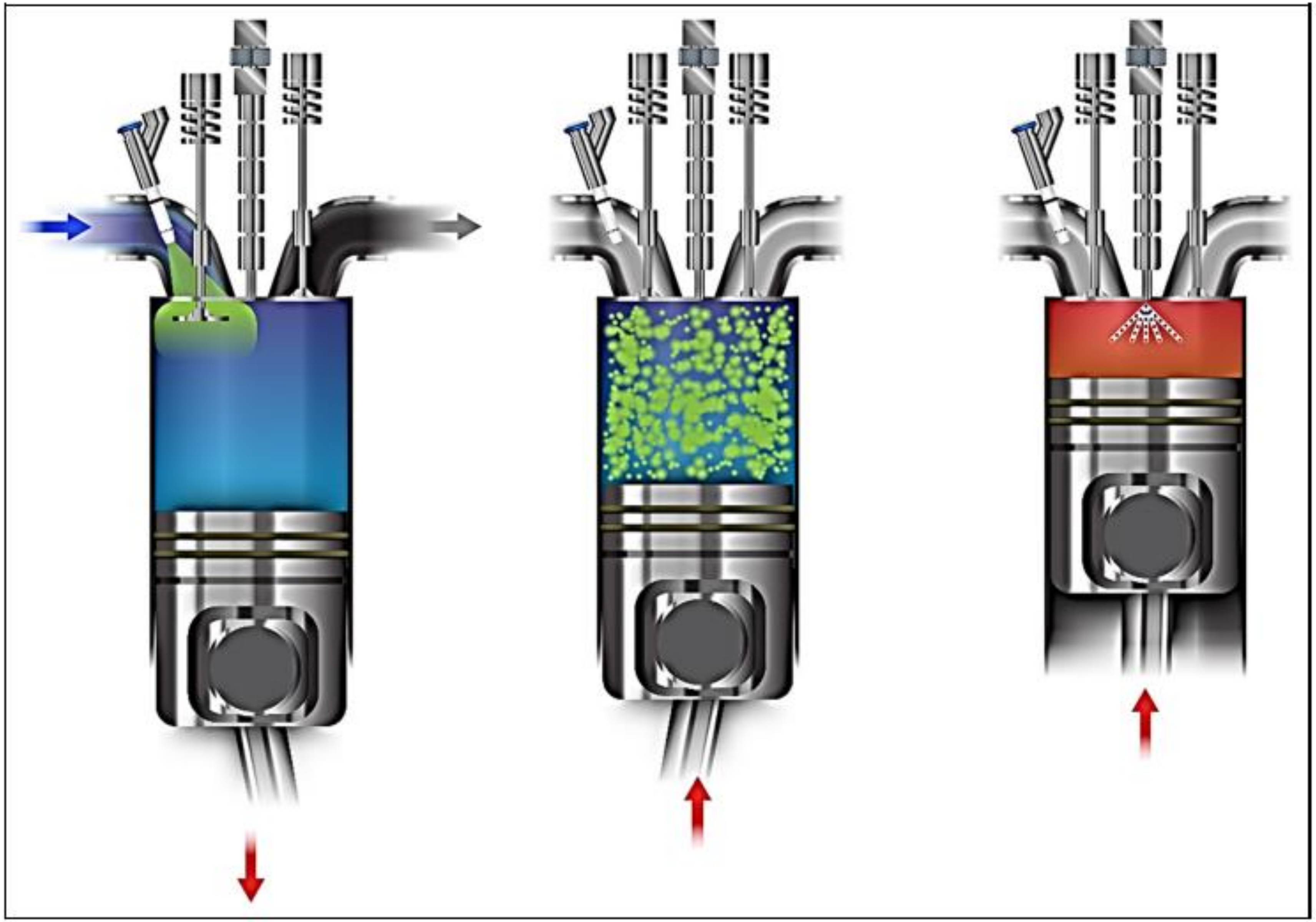
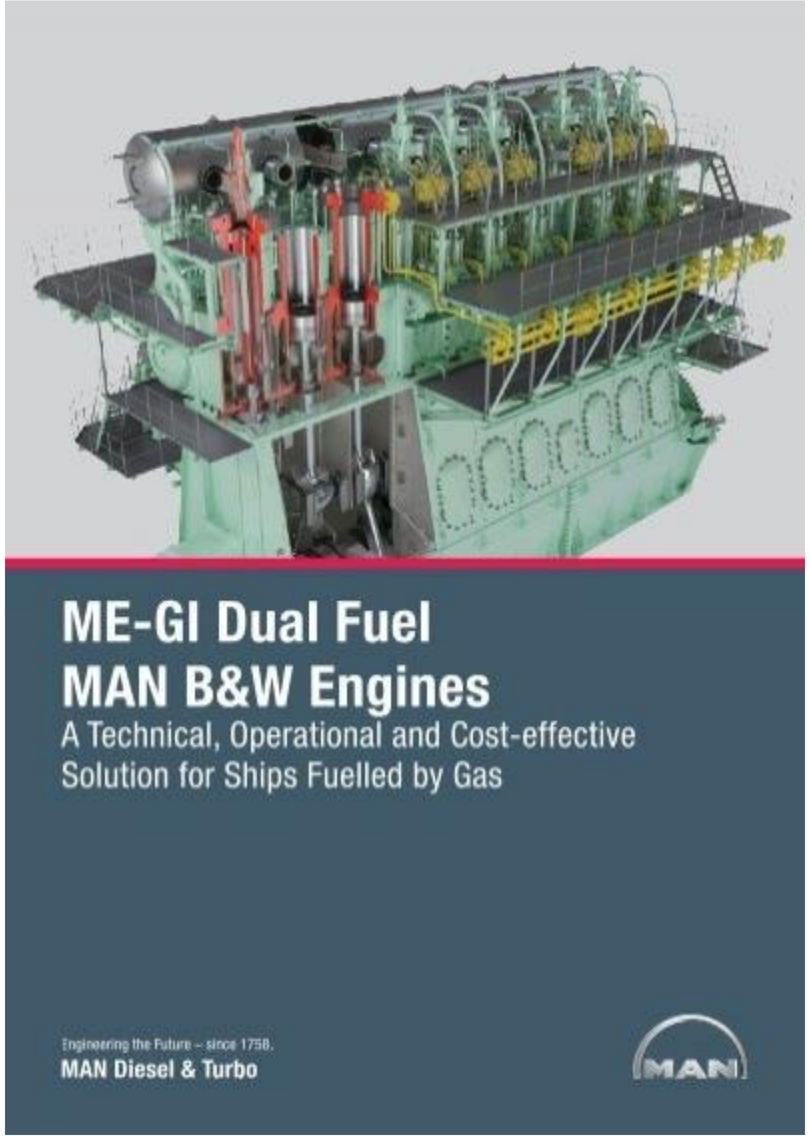


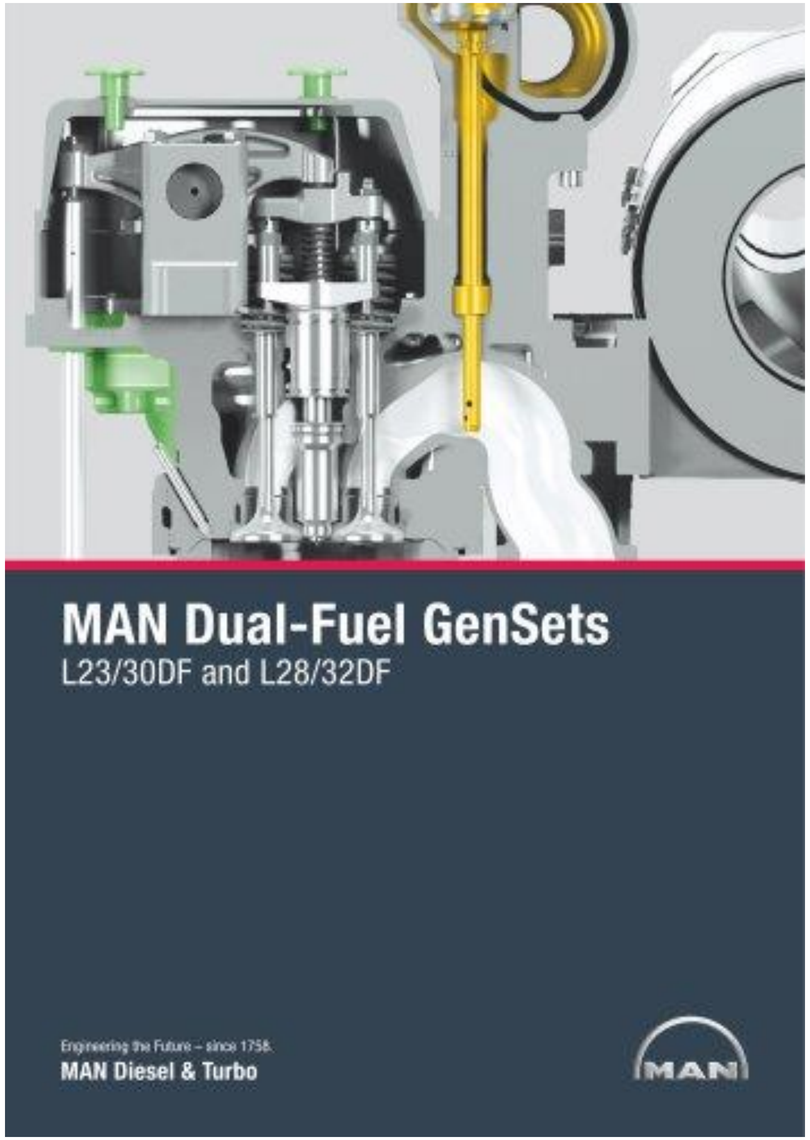
Fig. 1. The schematic diagram of dual fuel system. (CNG: compressed natural gas) [49].

DOĞALGAZ – CH4

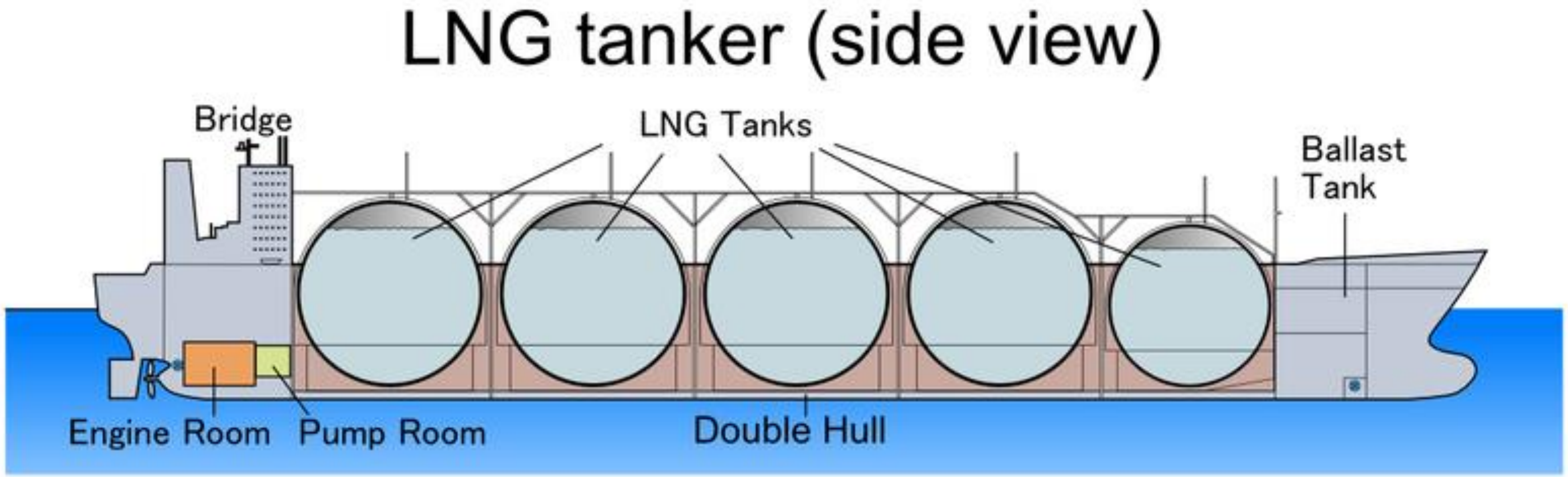


DOĞALGAZ – CH4

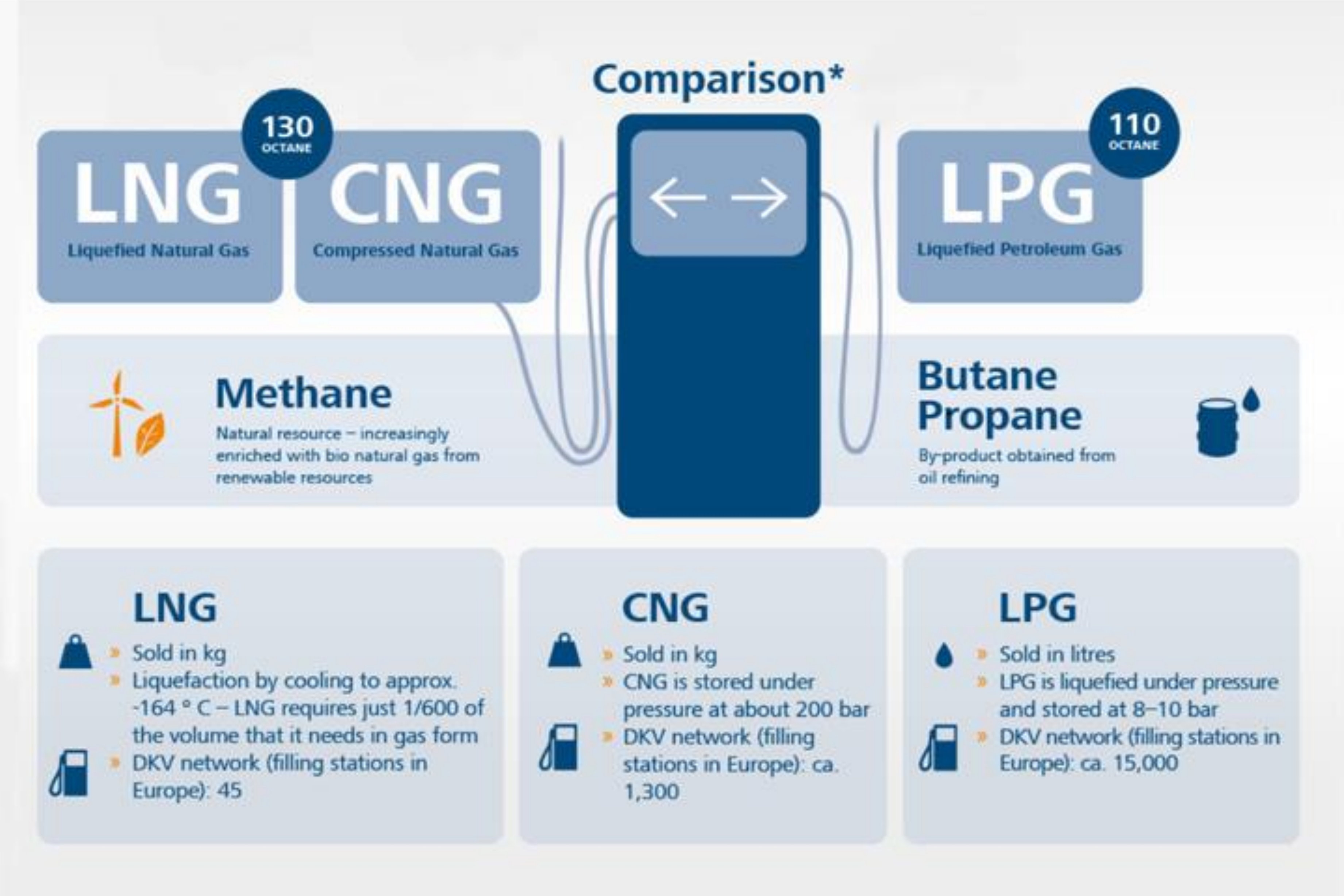




DOĞALGAZ – DEPOLAMA



DOĞALGAZ – CH4



HİDROJEN

HİDROJEN

IMO'nun emisyon azaltma hedefleri doğrultusunda denizcilik sektörü için potansiyel bir alternatif yakıt seçeneği olarak hidrojen (H2) uzun vadede en uygulanabilir yakıtlardan biridir. H2, yakıt pillerinde veya içten yanmalı motorlarda kullanılabilir (McKinlay, Turnock ve Hudson, 2020).

Halihazırda hidrojen kaynaklı yakıt pilleri ulaşım sektöründe, özellikle de otobüs gibi toplu taşıma araçlarında kullanılmaktadır. Örneğin, Londra hidrojen yakıtlı otobüsleri işletmeye başlamıştır (GOV.UK, 2020).

HİDROJEN

Çin, 2009 yılından bu yana H2 yakıtlı araçların kullanımını incelemektedir. Foshan Şehri, 2016 yılında Çin'deki ilk H2 altyapısı ve araç dağıtımında H2 ile çalışan toplu taşıma araçlarını işletmeye başlamıştır (Kendall vd., 2017).

World’s first hydrogen-powered tram goes into operation in China

By Boetius January 25, 2020 2428

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HİDROJEN

Hidrojen kaynaklı yakıt pilleri ve hidrojen kullanan motorlar, henüz ticari gemiler için ölçeklendirilmemiştir, halen geliştirme aşamasındadır, ancak 2016 yılında denizcilikte kullanım için başarıyla test edilmiştir (Shell, 2017).

World's first liquid-powered hydrogen ship, MF Hydra, is powered by Ballard's fuel cells

Hydrogen Fuel Cell Ships, #PoweredByBallard, Marine Technology, Marine News, Hydrogen Ferry, Marine Blogs

Oct. 9, 2023 — 3 minute read

Article by Betina Holtze

First Newbuild Inland Hydrogen Cargo Vessel Prepares to Enter Service

Antonie passed trials and is waiting for the installation of the hydrogen containers before enterign service (Concordia Damen)

MEDYADA HİDROJEN ☺

Elektrik Mühendisleri Odası
https://www.emo.org.tr › genel › bizden_detay

VESTEL'İN YAKIT PİLİ HAZIR (SABAH)

23 Ara 2006 — Yüngül, şunları söyledi: "**Yakıt** pilini hazırladık. Şubat ya da Mart ayında piyasa' tanıtacağız. Pil hemen tüm sektörlerde kullanılabilecek.

bigpara.hurriyet.com.tr
https://bigpara.hurriyet.com.tr › genel-haberler › veste...

Vestel: Hidrojen pili yaptık, 2006'da pazardayız - Bigpara

13 Tem 2005 — Bilgisayar, cep telefonu, sabit veya taşınabilir her türlü cihaza enerji sağlamak için geliştirilen **yakıt** pillerine patent aldıklarını söyleyen ...

Haber Bilim Teknoloji
https://www.haberbilimteknoloji.com › HABER

Lityum bataryalardan 10 kat daha verimli "yerli ...

30 Eki 2018 — ... **yakıt** pilleri geliştirildi. Prof. Dr. Nejat Veziroğlu Temiz Enerji Uygulama&Araştırma Merkezi ve **Vestel**'in iş birliğinde, yaklaşık 15 yıldır ...

Habertürk
https://www.haberturk.com › Ekonomi › Para

Vestel'in devrim pili - Makro Ekonomi Haberleri

Vestel'in **yakıt** pili teknolojisine sahip ilk nesil ürünlerin satışına şubat ayında başlanacak. Giriş: 15.12.2006 - 16:53 Güncelleme: 15.12.2006 - 16:53.

Yeni Şafak
https://www.yenisafak.com › teknoloji

10 kat daha dayanıklı yerli hidrojen yakıt pili geliştirildi

27 Eki 2018 — Prof. Dr. Nejat Veziroğlu Temiz Enerji Uygulama ve Araştırma Merkezi ile **Vestel** Savunma Sanayinin iş birliğinde, yaklaşık 15 yıldır devam eden ...

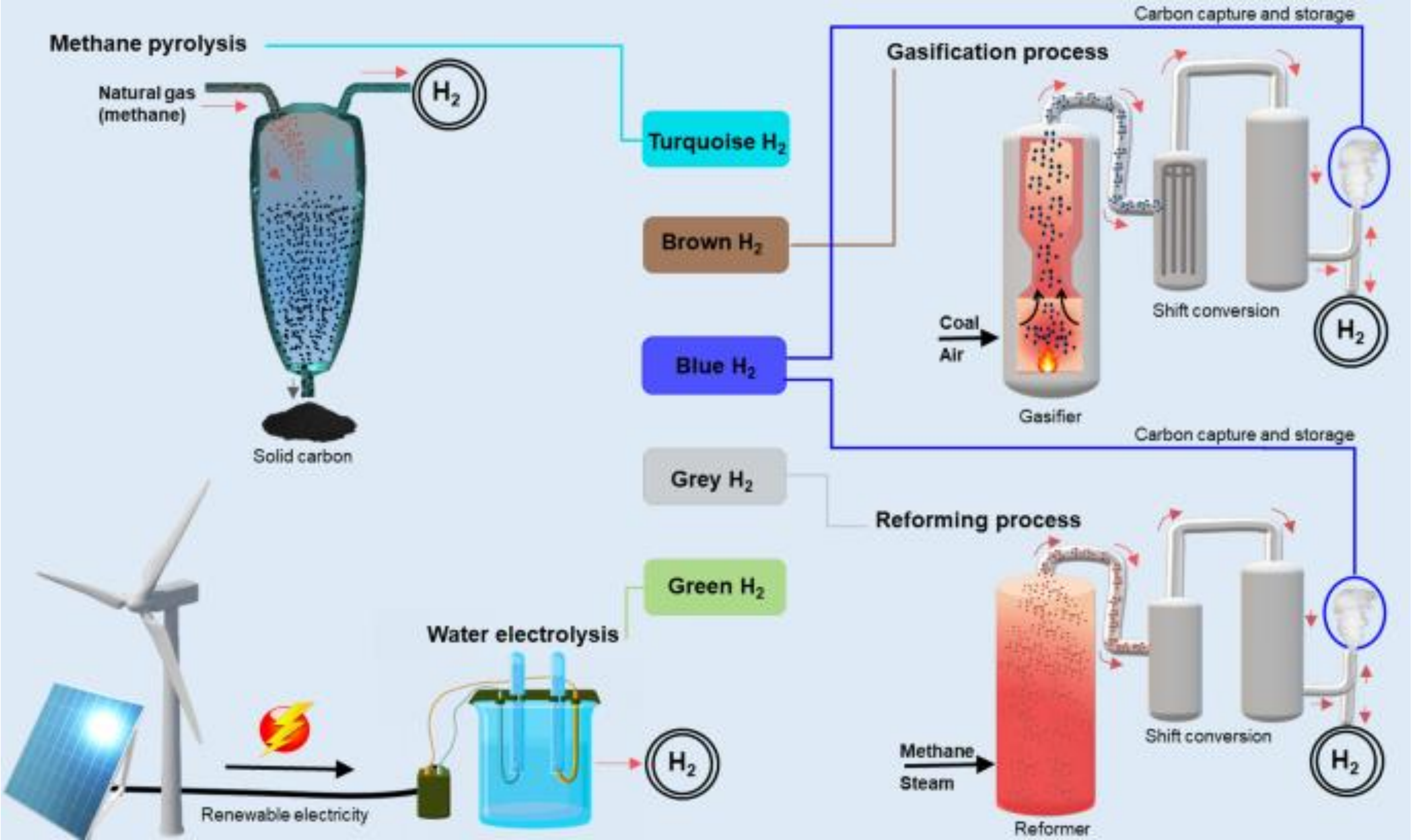
HİDROJEN

Group

Period	I	II											III	IV	V	VI	VII	VIII
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
8	119 Uun																	

* Lanthanides	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
** Actinides	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

HİDROJEN ÜRETİMİ



HİDROJEN ÜRETİMİ

Üretim metoduna göre,

Grey (Fosil yakıtlardan üretilen),

Blue (Karbon yakalama (Steam Reforming) teknolojisiyle),

Green (Elektroliz ile sudan),

Purple/pink (Nükleer),

Black (Kömürden),

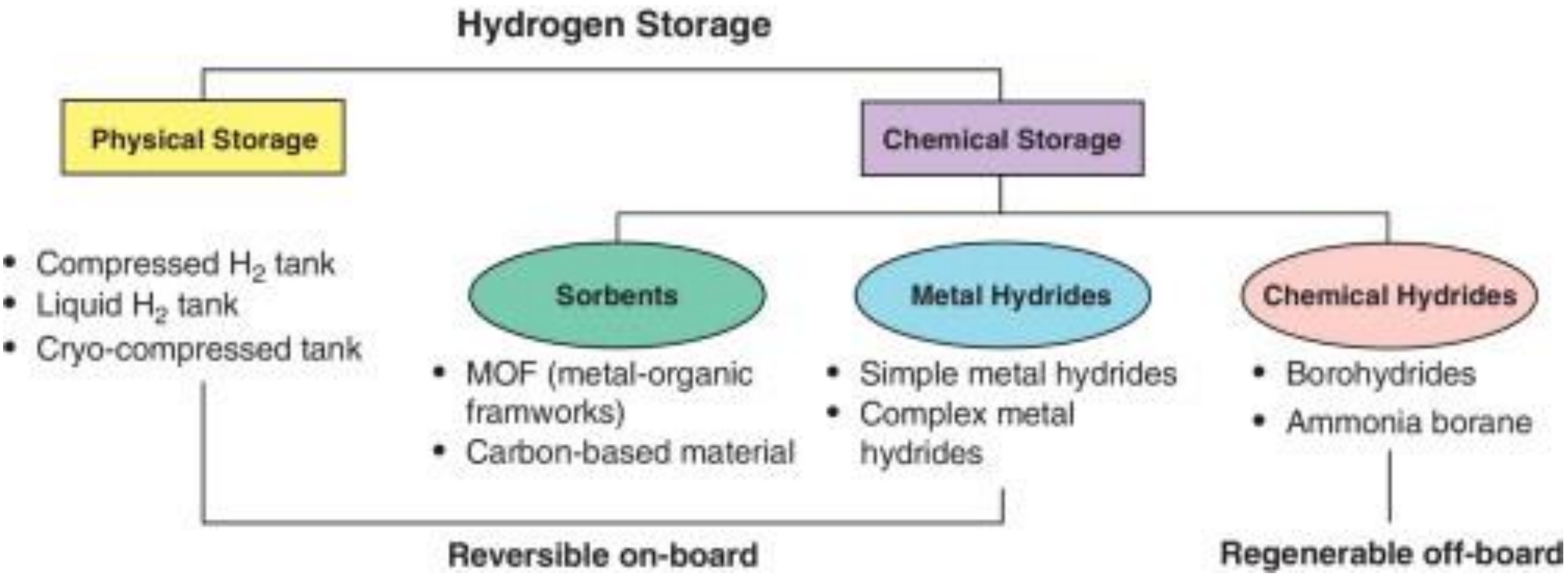
Turkuaz (Metane pirolizi)

Bu gün üretilen hidrojenin %95'i doğalgazın buhar dönüşümü (steam reforming) ile üretilmektedir.

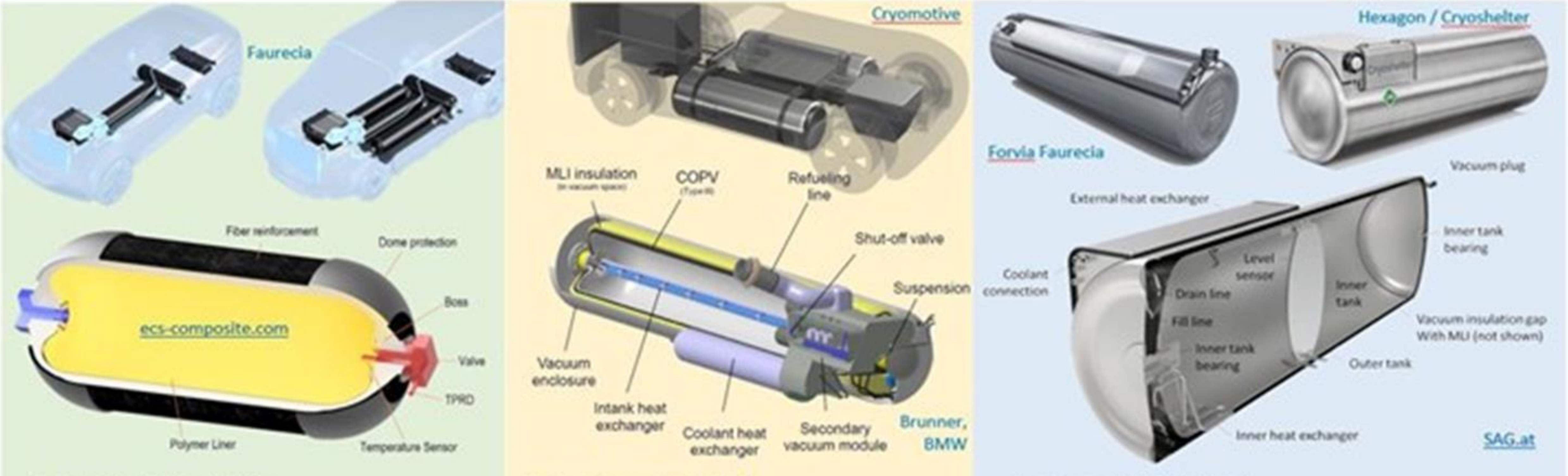
HİDROJEN DEPOLAMA

Hydrogen Carrier	Molecular formula	Molecular mass (g/mol)	Density (kg/m^3)	Gravimetric H_2 content (wt. %)	Volumetric H_2 content ($kg\text{-}H_2/m^3$)
H_2 Compressed	H_2	2.0	42.0	100.0	42.0
H_2 Liquid	H_2	2.0	71.0	100.0	71.0
Diesel	$C_{12}H_{26}$	170.3	750.0	15.4	115.4
Toluene	C_7H_8	92.1	888.0	8.8	77.7
Methanol	CH_3OH	32.0	792.0	12.6	99.7
Ammonia	NH_3	17.0	681.9	17.8	121.1
Magnesium hydride	MgH_2	26.3	1450.0	7.7	111.1
Sodium aluminium hydride	$NaAlH_4$	54.0	905.0	7.5	67.6
Ammonia Borane	NH_3BH_3	30.9	780.0	19.6	152.8
Sodium Borohydride	$NaBH_4$	37.8	1070.0	10.7	114.0

HİDROJEN DEPOLAMA

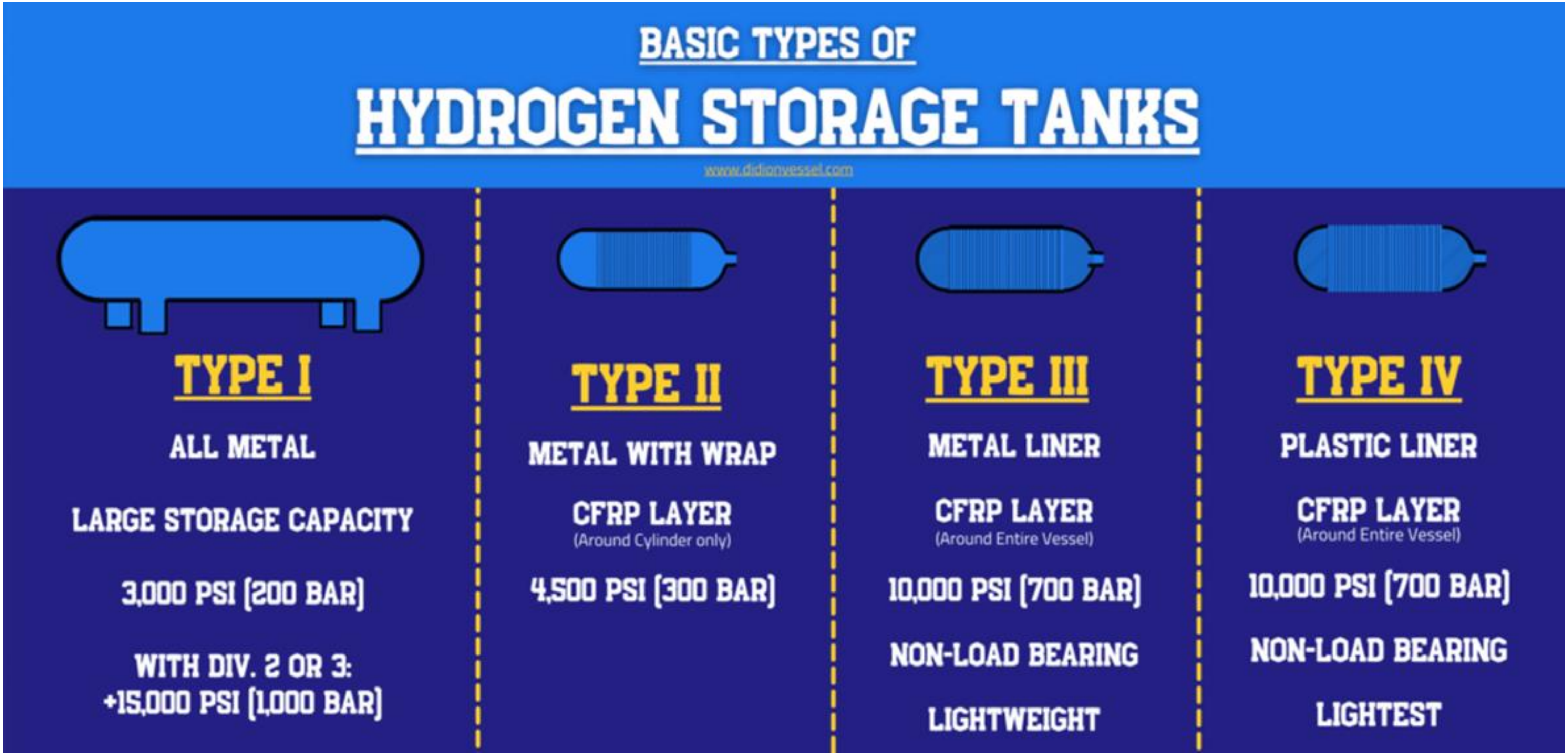


HİDROJEN DEPOLAMA

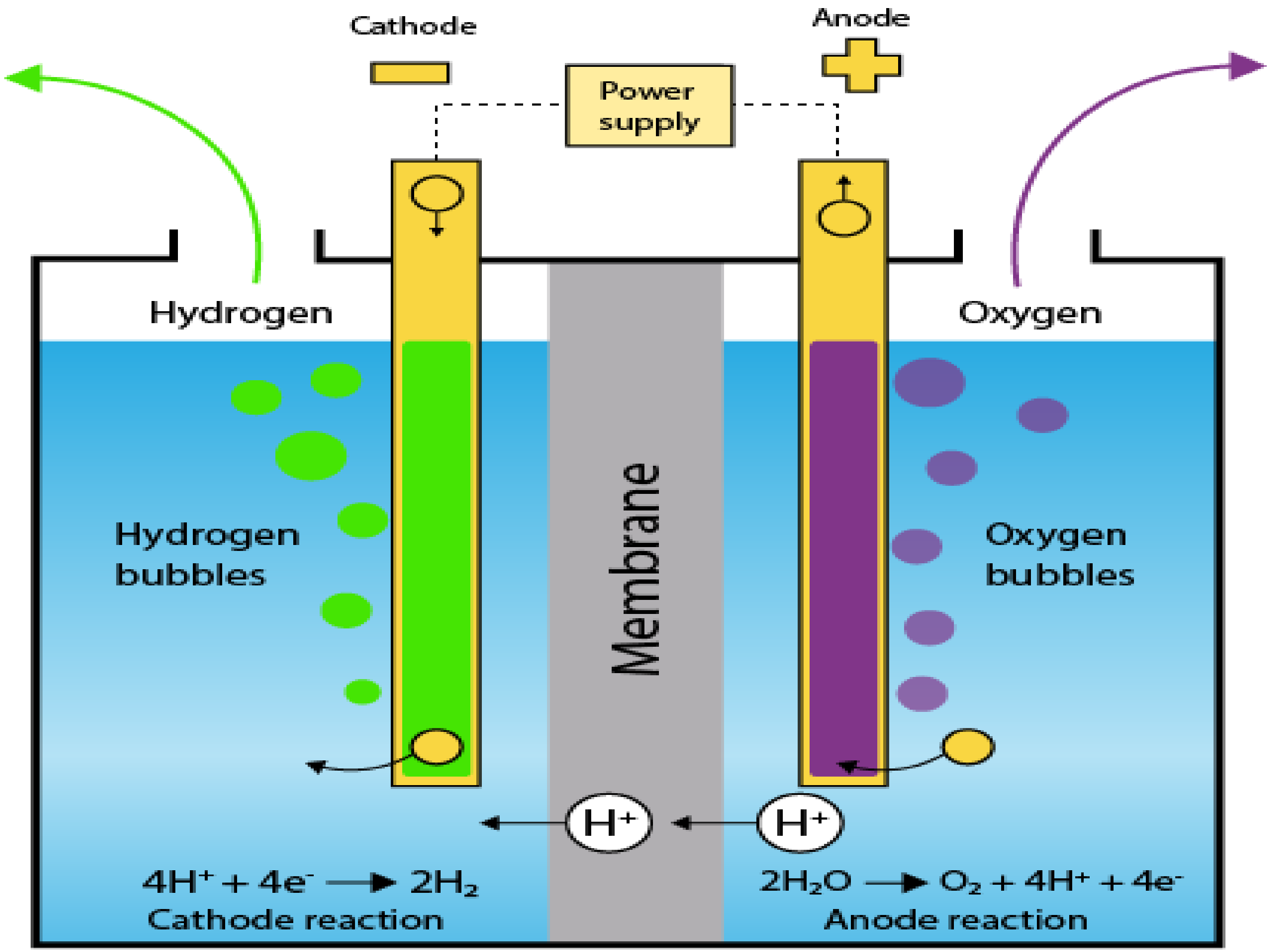


Compressed Gas (CGH_2)	Cryo-compressed (CcH_2)	Subcooled Liquid (sLH_2)
Type IV	Type III inner/MLI + vacuum/metal outer	Type I inner/MLI + vacuum/metal outer
350 – 1,000 bar | 290 K/ 17°C	350-400 bar | 20-340 K/ -253 to 67°C	< 16 bar | 28 K/ -245°C
40 kg/m³ | Carbon Fiber: 1	72 kg/m³ | Carbon Fiber: 0.20	62 kg/m³ | Carbon Fiber: 0

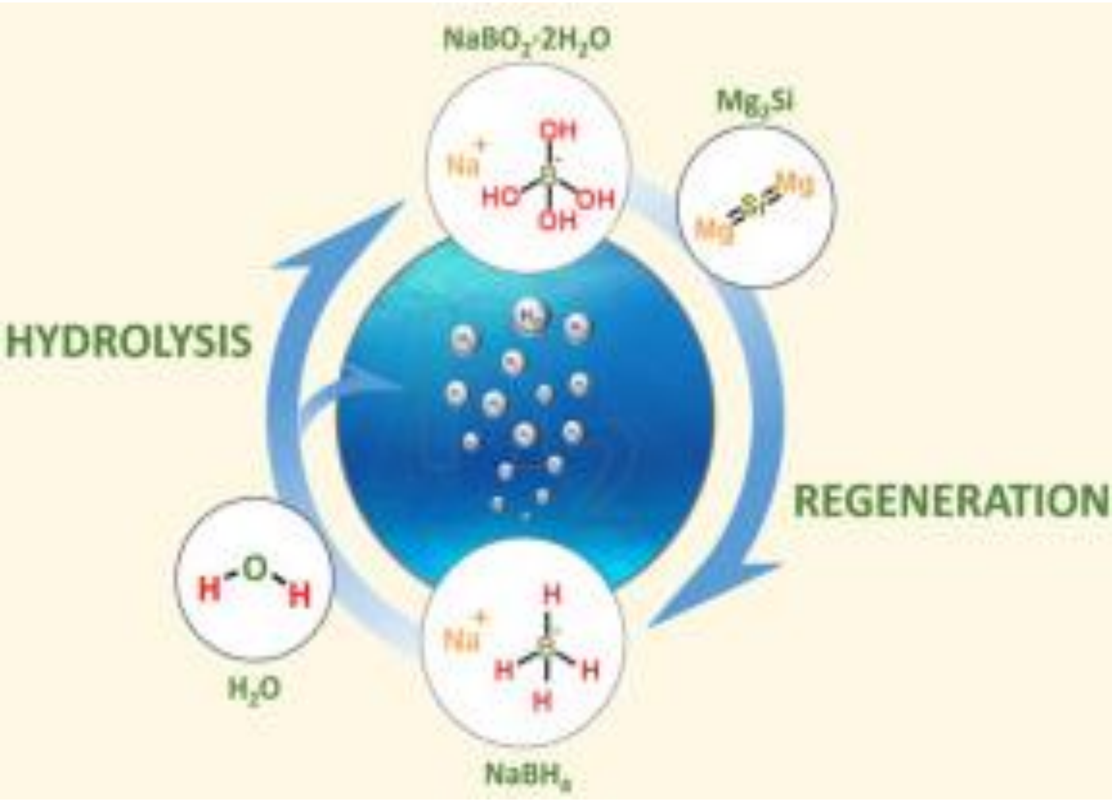
HİDROJEN DEPOLAMA

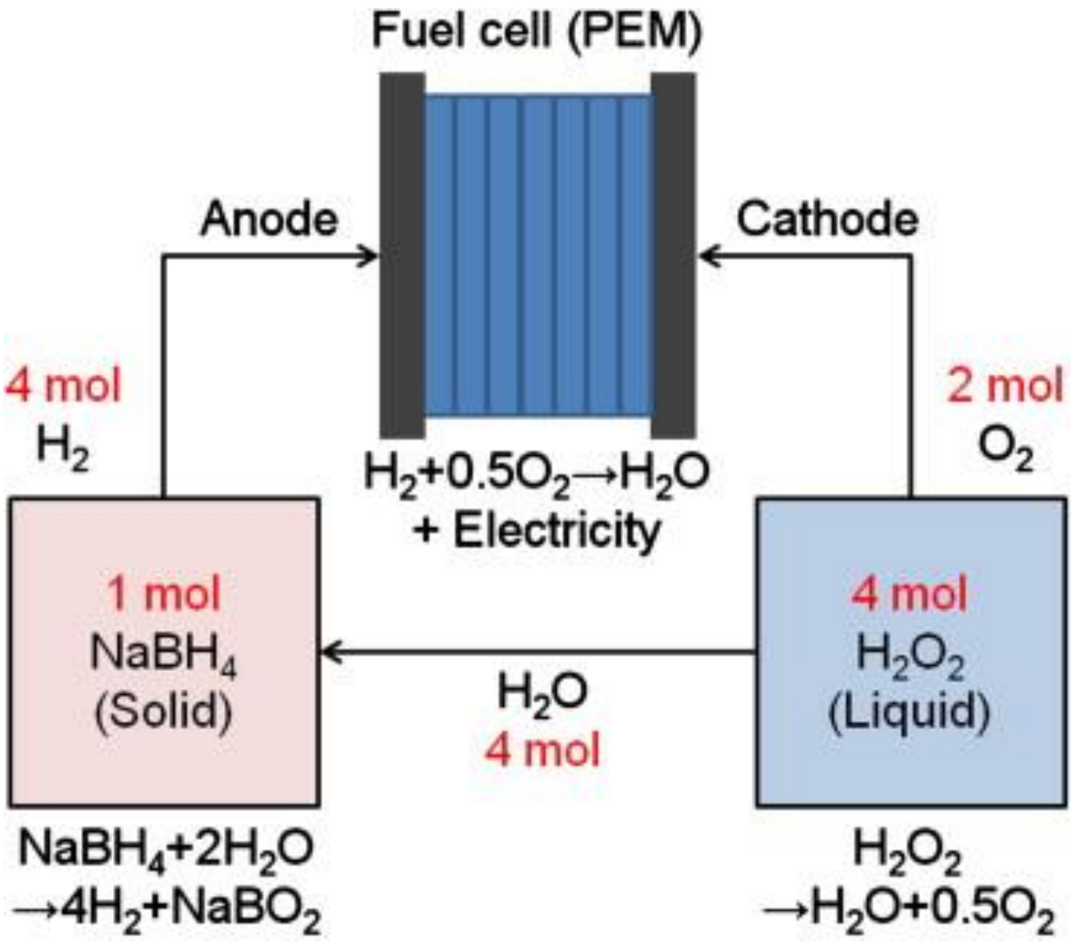


HİDROJEN DEPOLAMA – KLASİK ELEKTROLİZ



HİDROJEN DEPOLAMA





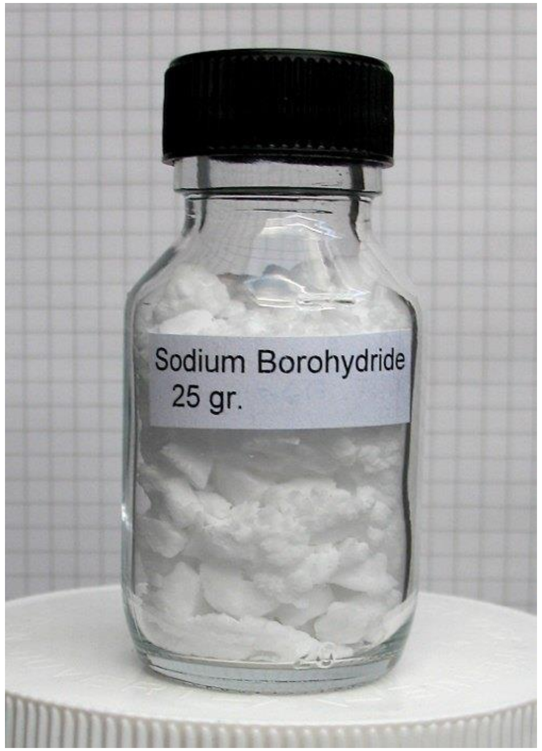
Overall reaction

$NaBH_4 + 4H_2O_2 \rightarrow 4H_2 + 2O_2 + 2H_2O + NaBO_2$

$NaBH_4 + 4H_2O_2 \rightarrow 6H_2O + NaBO_2 + 8e^-$

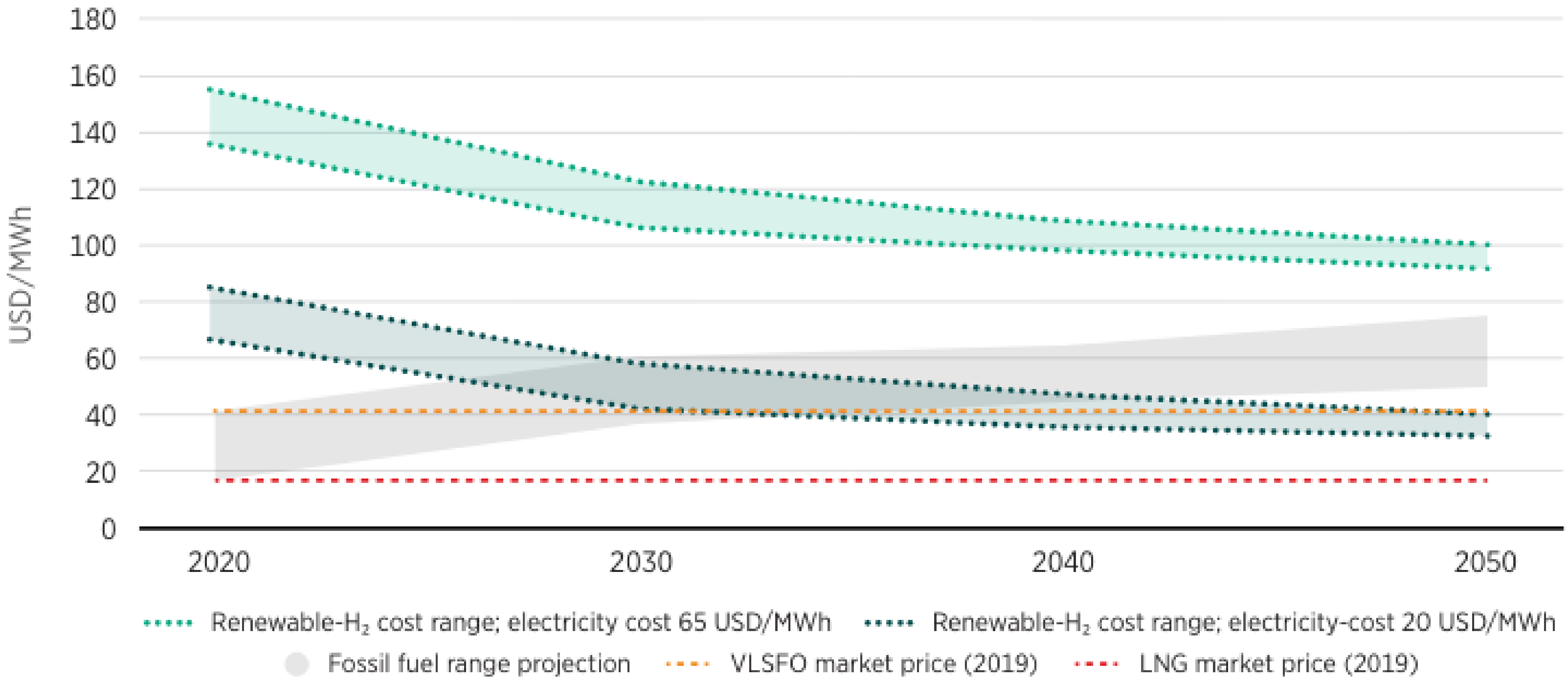
HİDROJEN DEPOLAMA

Alfa Aesar	035788	Sodium borohydride, 97+%	100g	**$81.9**
Alfa Aesar	013432	Sodium borohydride, 98%	100g	**$84**
Alfa Aesar	088983	Sodium borohydride, 98% min	100g	**$85.9**



HİDROJEN MALİYETLERİ

Figure 18 **Green H_2 cost projections**



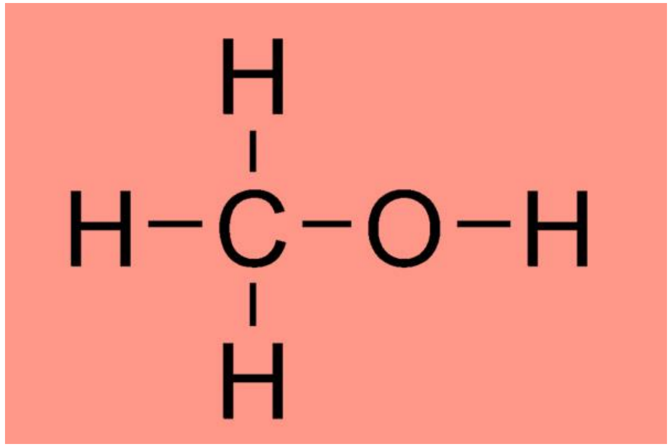
METANOL

METANOL – CH3OH

Denizcilik için alternatif bir yakıt olarak bilinen metanol, son yıllarda artan bir ilgi görmektedir.

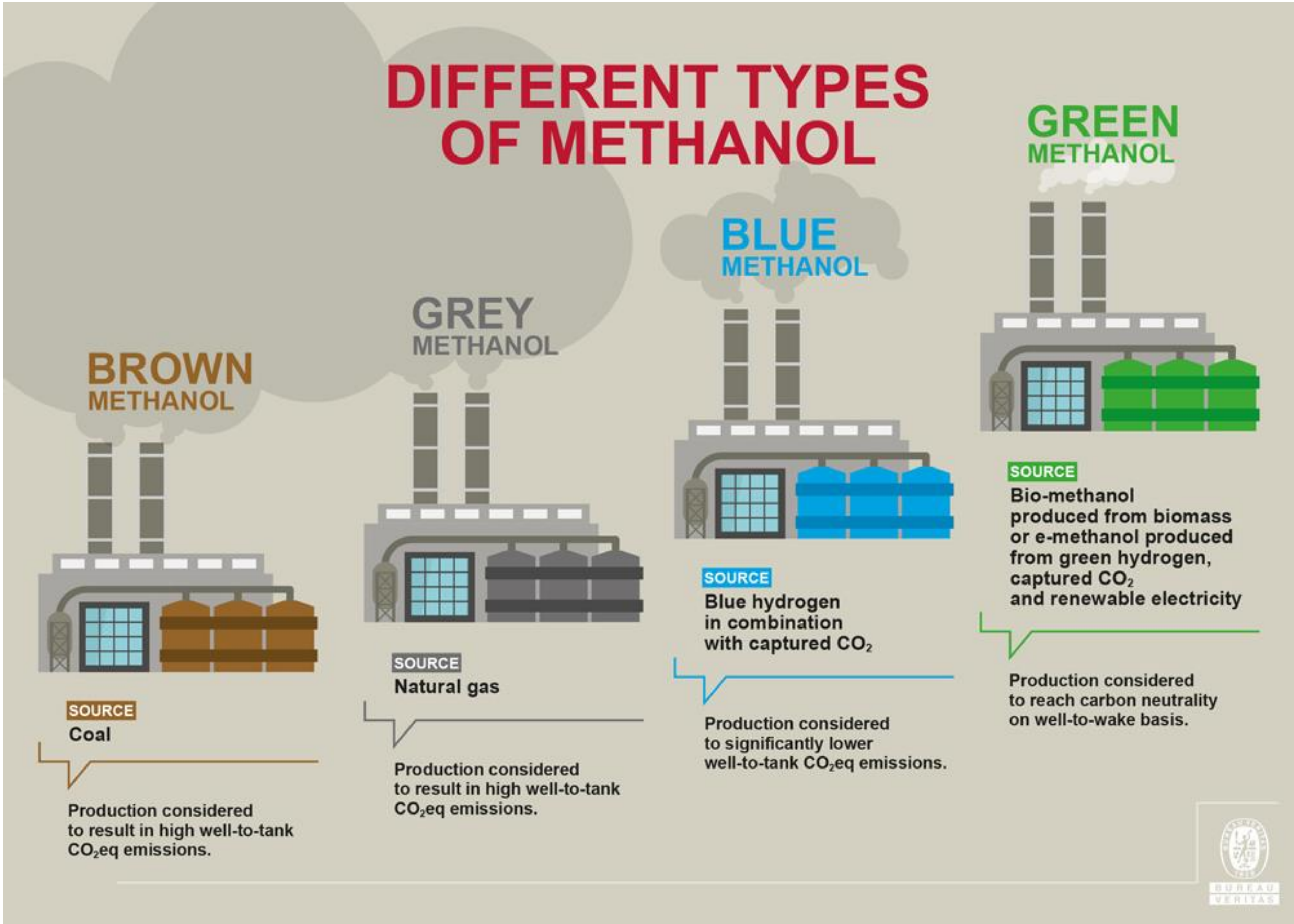
Bu alkol, diğer yakıtlara kıyasla en düşük karbon ve en yüksek H2 içeriklerinden birine sahiptir.

Ayrıca metanol, sülfür oksit (SOx) ve NOx emisyonlarını HFO'ya kıyasla %60'a kadar azaltmakta (ITF, 2018) ve partikül madde emisyonlarını %95 oranında düşürmektedir (Methanex, 2020).

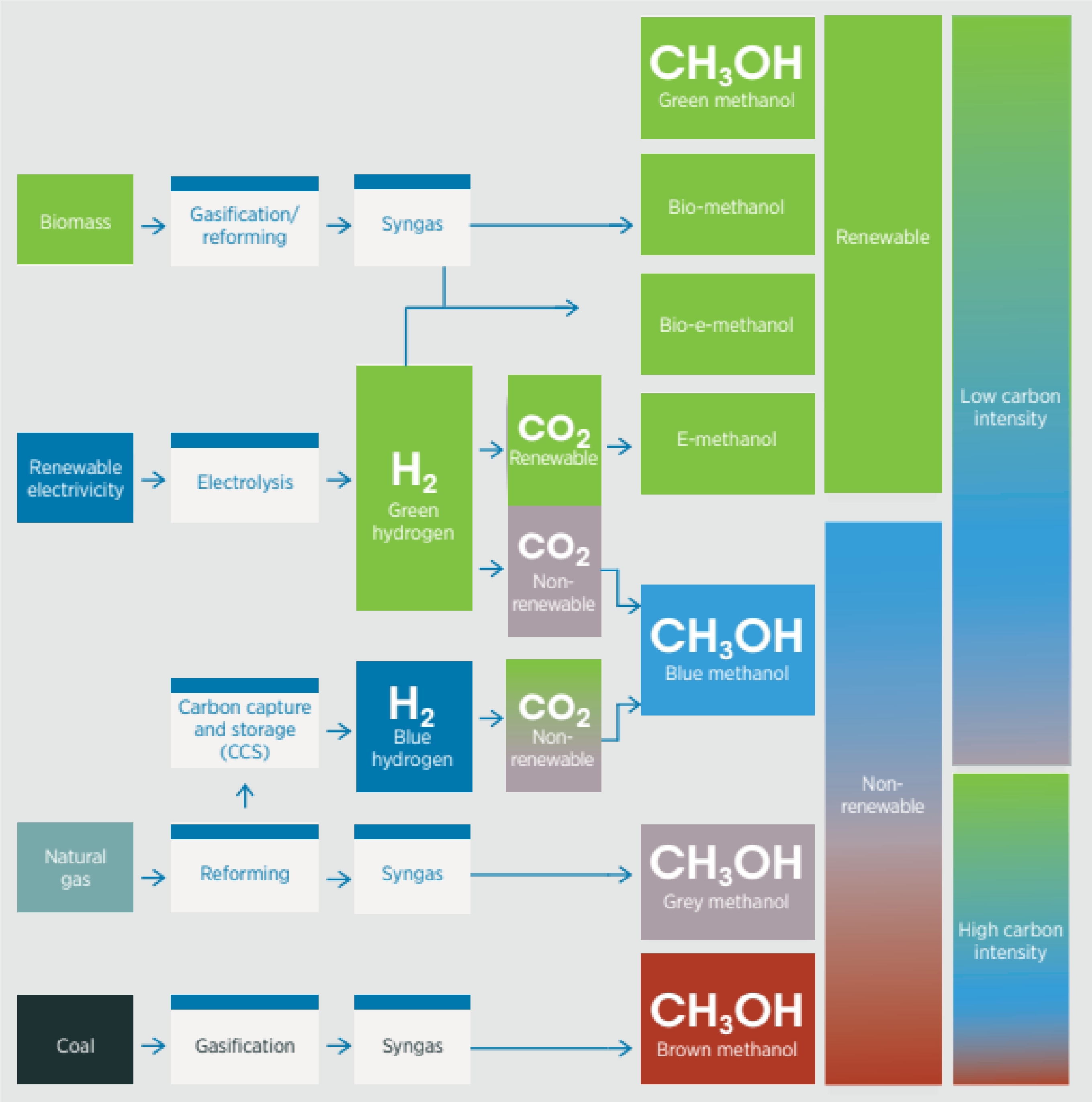


METANOL – CH3OH

Şu anda metanolün çoğu kömür veya NG'den üretilmektedir, ancak metanol tarımsal atıklar gibi lignoselülozik hammaddelerden, biyo-metanol üretmek için sürdürülebilir şekilde yönetilen ormanlardan toplanan biyokütleden veya kentsel katı atıkların gazlaştırılmasından da üretilebilir.

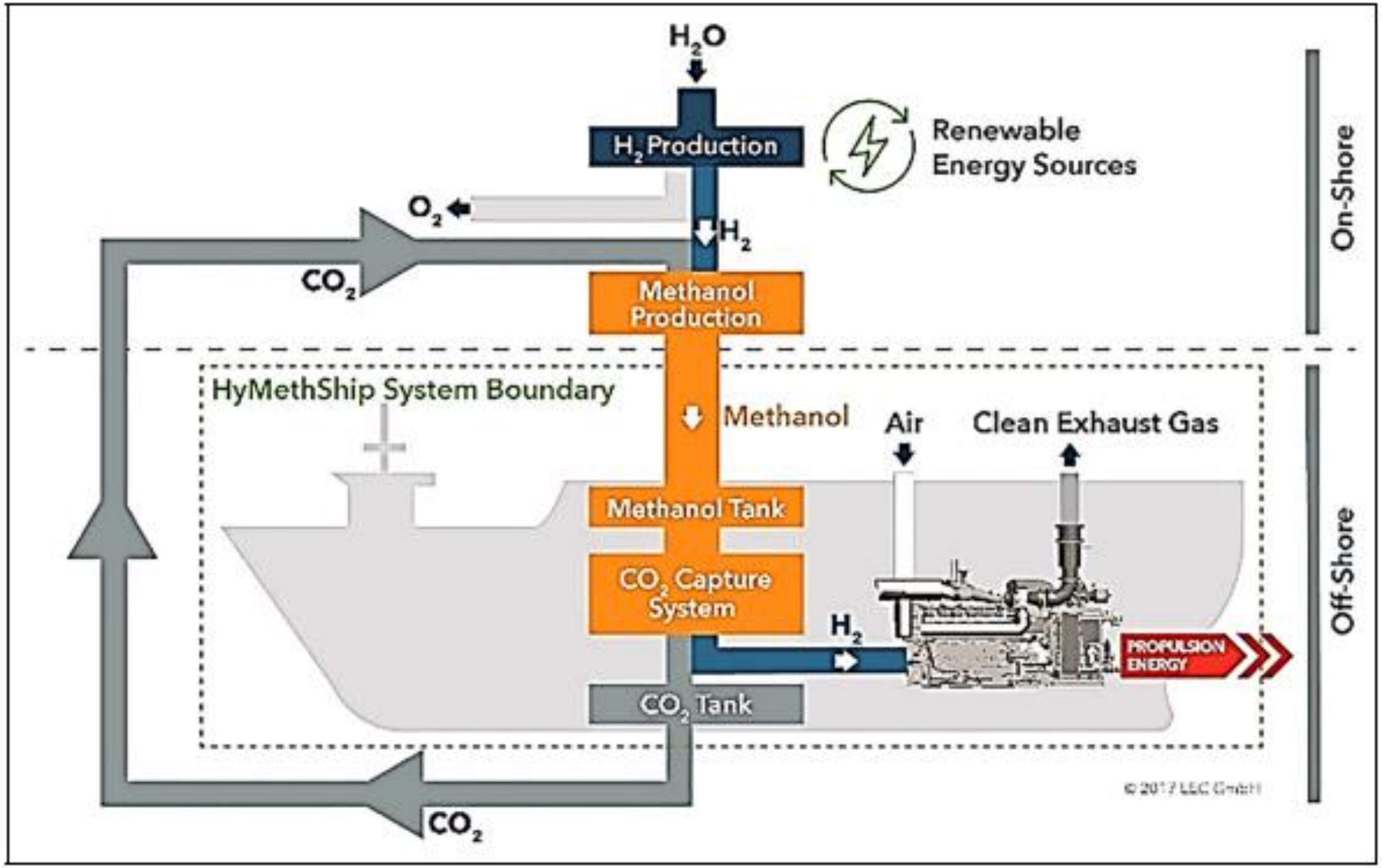


DIFFERENT TYPES OF METHANOL
BROWN METHANOL
SOURCE
Coal
Production considered to result in high well-to-tank CO_2eq emissions.
GREY METHANOL
SOURCE
Natural gas
Production considered to result in high well-to-tank CO_2eq emissions.
BLUE METHANOL
SOURCE
Blue hydrogen in combination with captured CO_2
Production considered to significantly lower well-to-tank CO_2eq emissions.
GREEN METHANOL
SOURCE
Bio-methanol produced from biomass or e-methanol produced from green hydrogen, captured CO_2 and renewable electricity
Production considered to reach carbon neutrality on well-to-wake basis.
BUREAU VERITAS



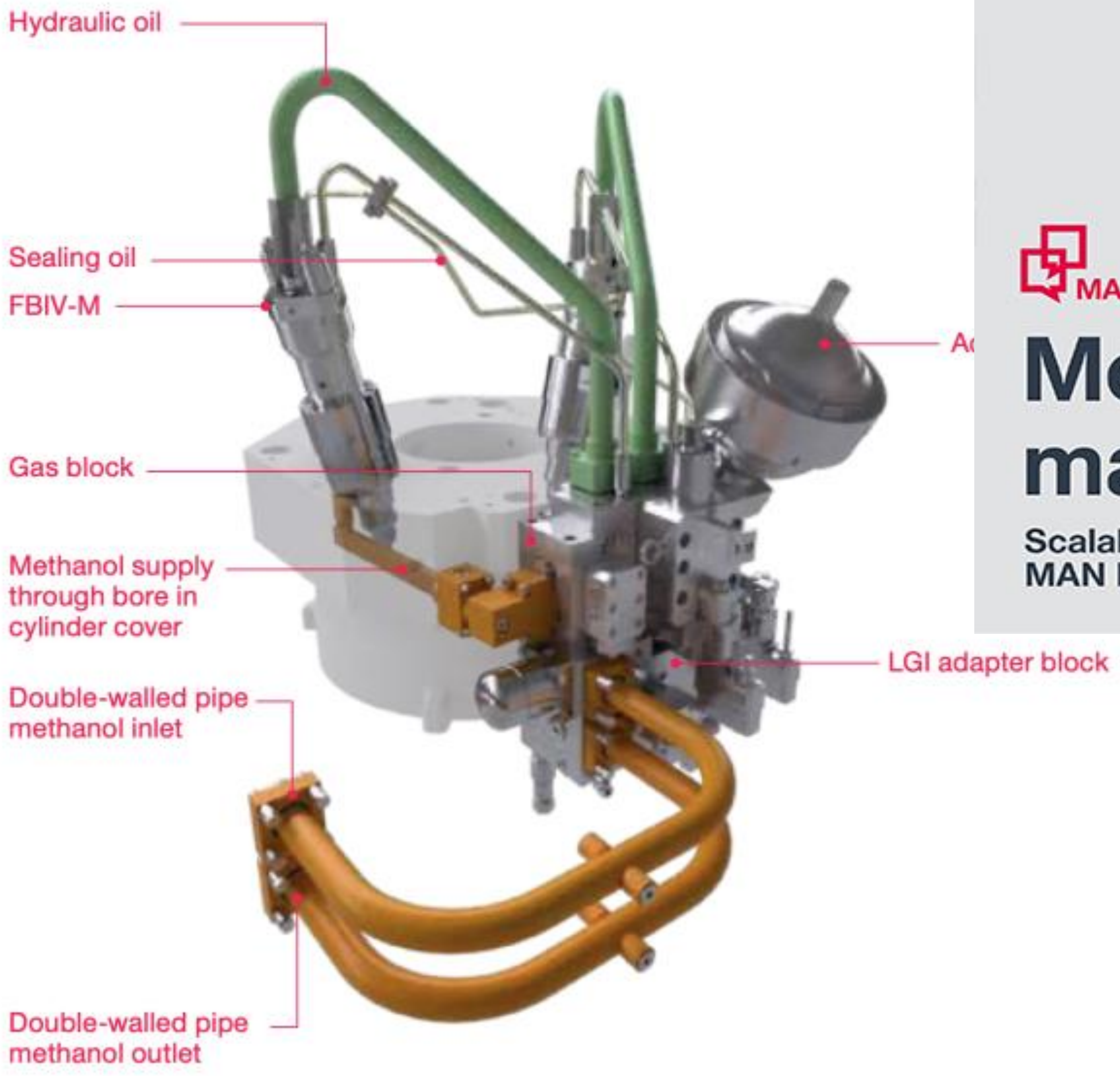
Biomass
Gasification/ reforming
Syngas
Renewable electricity
Electrolysis
H_2 Green hydrogen
CO_2 Renewable
CO_2 Non-renewable
Carbon capture and storage (CCS)
H_2 Blue hydrogen
CO_2 Non-renewable
Natural gas
Reforming
Syngas
Coal
Gasification
Syngas
CH_3OH Green methanol
Bio-methanol
Bio-e-methanol
E-methanol
CH_3OH Blue methanol
CH_3OH Grey methanol
CH_3OH Brown methanol
Renewable
Non-renewable
Low carbon intensity
High carbon intensity

METANOL



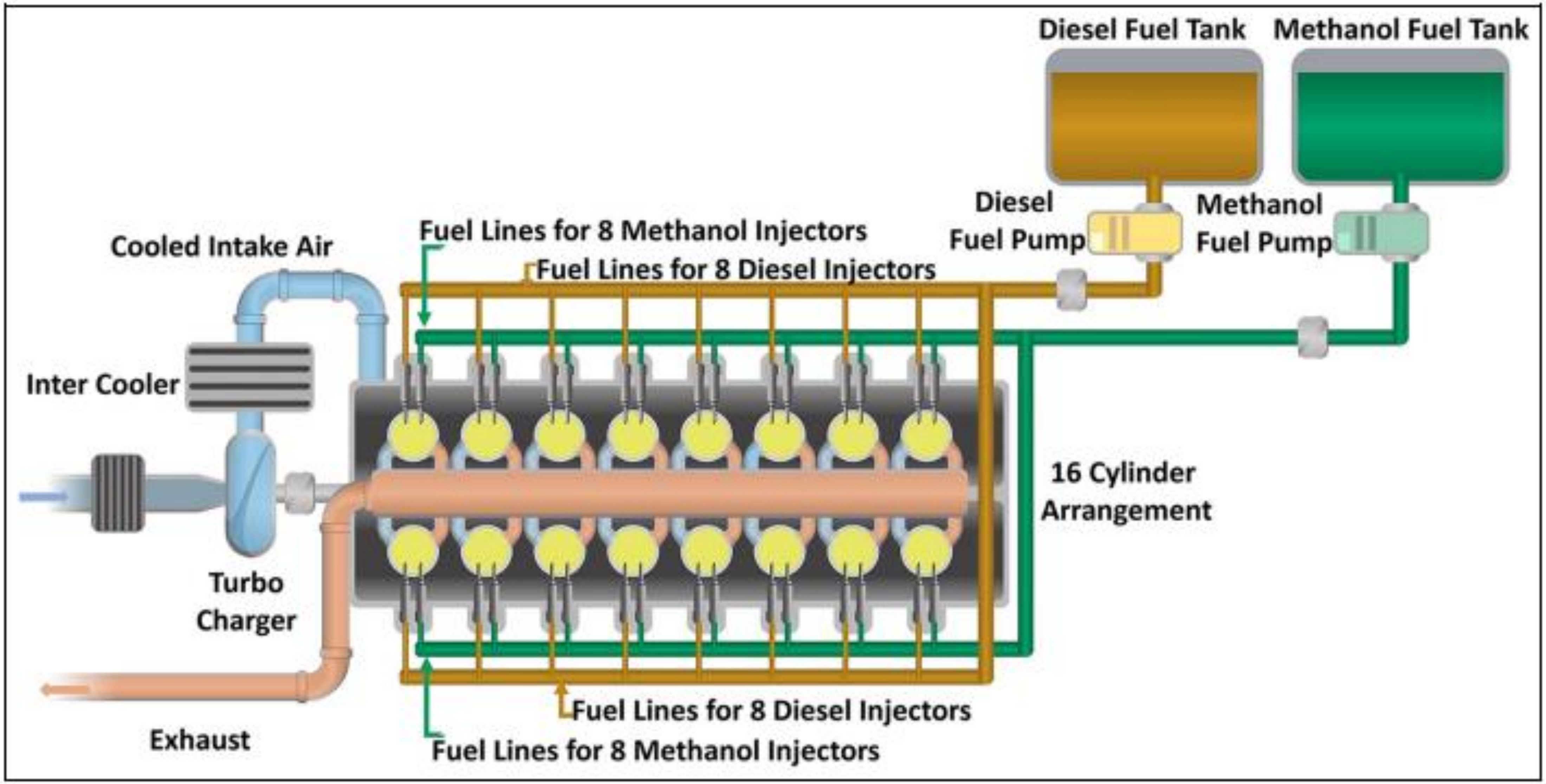
H_2O
H_2 Production
Renewable Energy Sources
O_2
H_2
CO_2
Methanol Production
On-Shore
HyMethShip System Boundary
Methanol
Air
Clean Exhaust Gas
Methanol Tank
CO_2 Capture System
H_2
PROPULSION ENERGY
CO_2 Tank
Off-Shore
CO_2

METANOL


Hydraulic oil
Sealing oil
FBIV-M
Gas block
Methanol supply through bore in cylinder cover
Double-walled pipe methanol inlet
Double-walled pipe methanol outlet
LGI adapter block

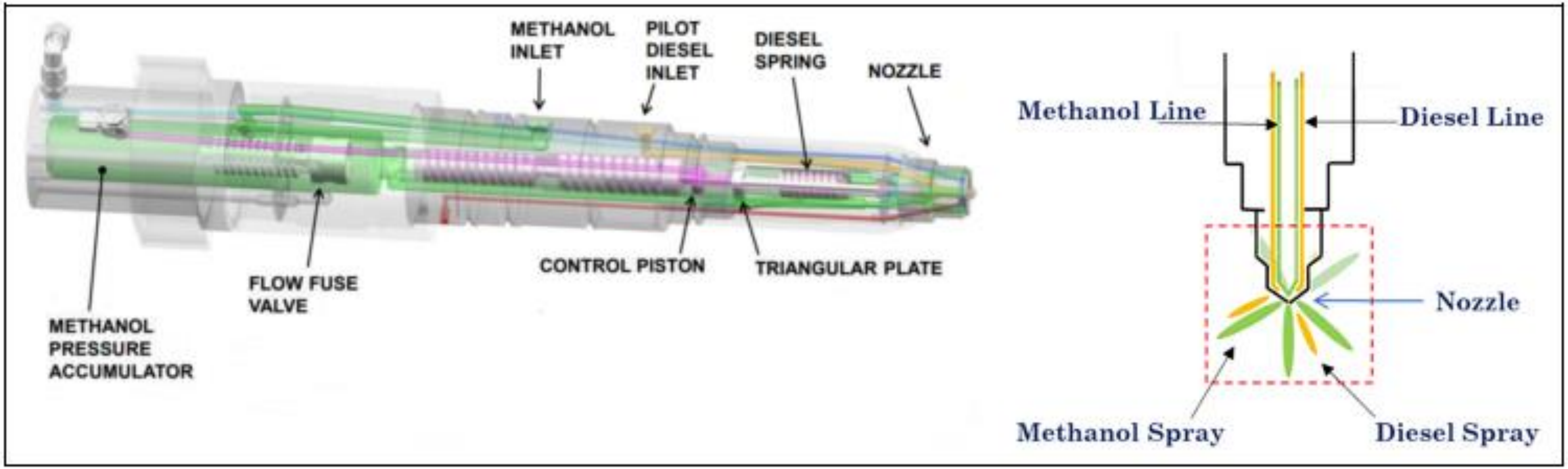

MAN ExpertTalks
Methanol as marine fuel
Scalable energy transition with MAN B&W ME-LGIM
MAN

METANOL



Diesel Fuel Tank
Methanol Fuel Tank
Diesel
Fuel Pump
Methanol
Fuel Pump
Fuel Lines for 8 Methanol Injectors
Fuel Lines for 8 Diesel Injectors
Cooled Intake Air
Inter Cooler
16 Cylinder
Arrangement
Turbo
Charger
Exhaust
Fuel Lines for 8 Diesel Injectors
Fuel Lines for 8 Methanol Injectors

METANOL


METHANOL INLET
PILOT DIESEL INLET
DIESEL SPRING
NOZZLE
CONTROL PISTON
TRIANGULAR PLATE
FLOW FUSE VALVE
METHANOL PRESSURE ACCUMULATOR
Methanol Line
Diesel Line
Nozzle
Methanol Spray
Diesel Spray

METANOL

Shipping giant Maersk unveils world's first vessel using green methanol

PUBLISHED THU, SEP 14 2023·1:02 AM EDT | UPDATED MON, SEP 25 2023·1:30 AM EDT

Silvia Amaro
@SILVIA_AMARO

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KEY POINTS

- The new container ship, ordered in 2021, has two engines: one moved by traditional fuels and another run with green methanol — an alternative component, which uses biomass or captured carbon and hydrogen from renewable power.
- Practically speaking, the new vessel emits 100 tons of carbon dioxide less per day compared to diesel-based ships.
- "It's a really symbolic day of our energy transition, really becoming a reality, something concrete that we can actually demonstrate, not just commitments and hard work, but actually something that everybody can see," Maersk CEO Vincent Clerc told CNBC.

TotalEnergies

METANOL

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MAN Energy Solutions

Our focus Energy & Storage Marine Process Industry Oil & Gas Services

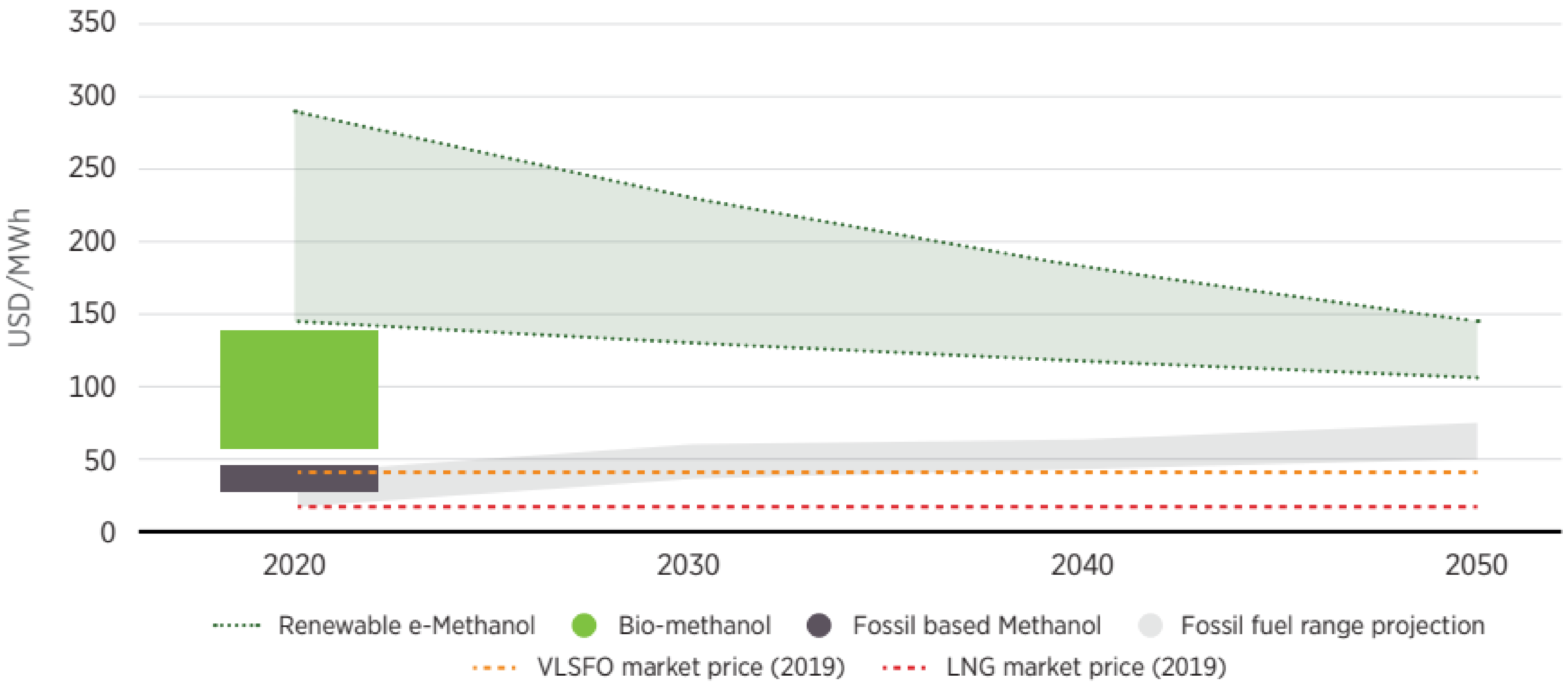
Methanol-fueled ships: Testing of an ME-LGIM engine in Korea

As the world races to decarbonize amid rising temperatures and intensifying heatwaves, the global shipping industry has struggled to wean itself off heavy fuel oil. But now in South Korea, MAN Energy Solutions and HD Hyundai Heavy Industries – Engine and Machinery Division are building large-scale engines for container ships that can run on green methanol – a key signal to the shipping industry that climate-neutral fuels are about to take over and the technologies enabling the transition are available today.

By Tim Hornyak

METANOL MALİYETLERİ

Figure 20 **Methanol cost projections**



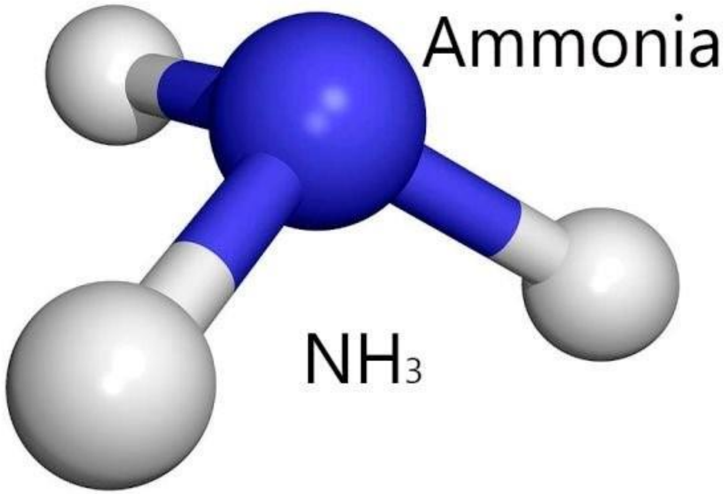
AMONYAK

AMONYAK – NH3

En çok umut vaat eden alternatif nakliye yakıtlarından biri karbonsuz amonyaktır. IMO'nun sera gazı emisyon hedeflerine ulaşmak için yaygın bir araç olarak lanse edilmektedir (Kim ve ark., 2020).

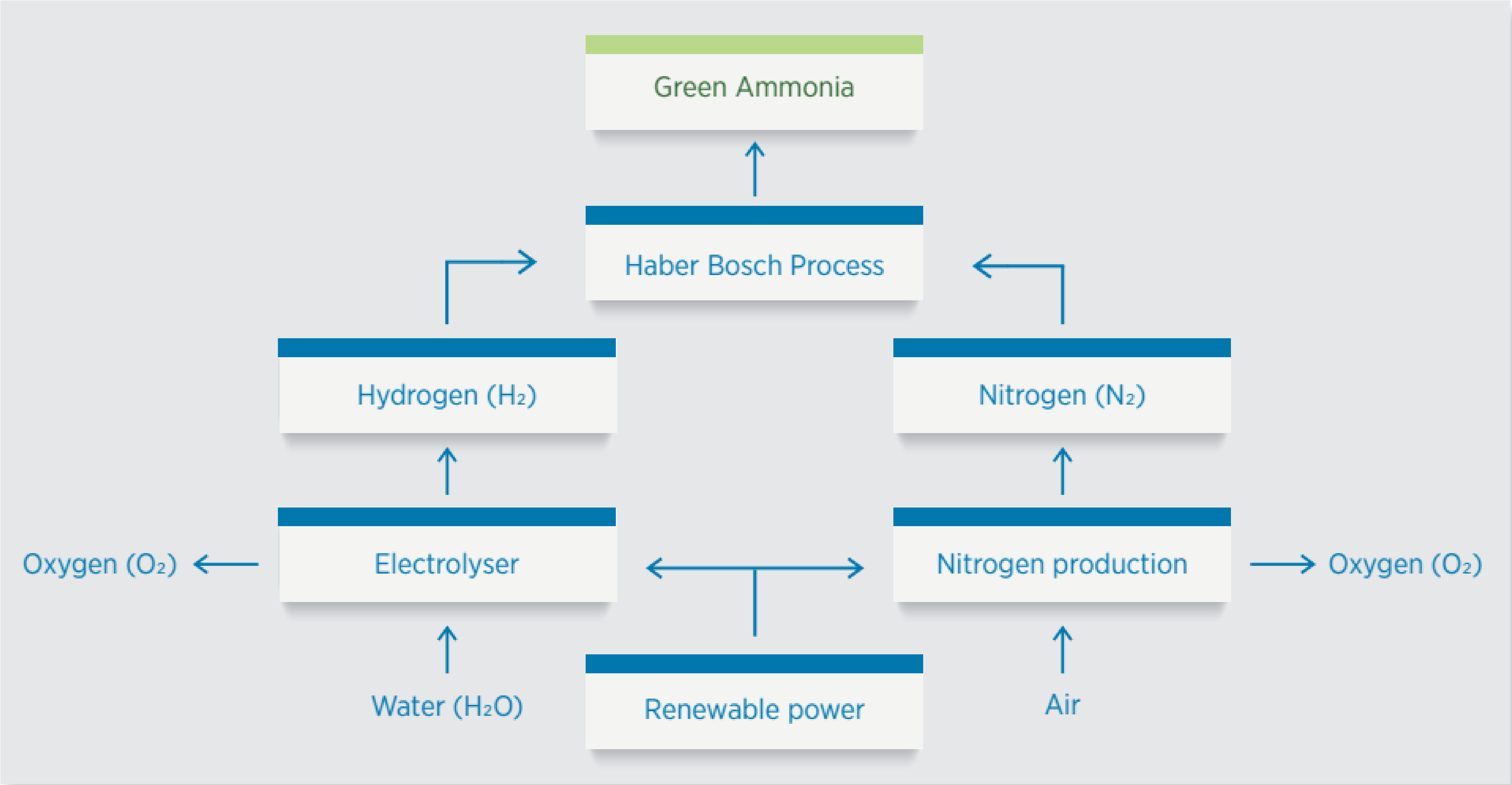
Son zamanlarda yapılan çalışmalar, amonyak üretiminin yenilenebilir enerji kaynaklı elektroliz çalışmalarında oldukça faydalı olacaktır. Denizcilik sektörünün derinlemesine karbonsuzlaştırılmasını sağlamak.

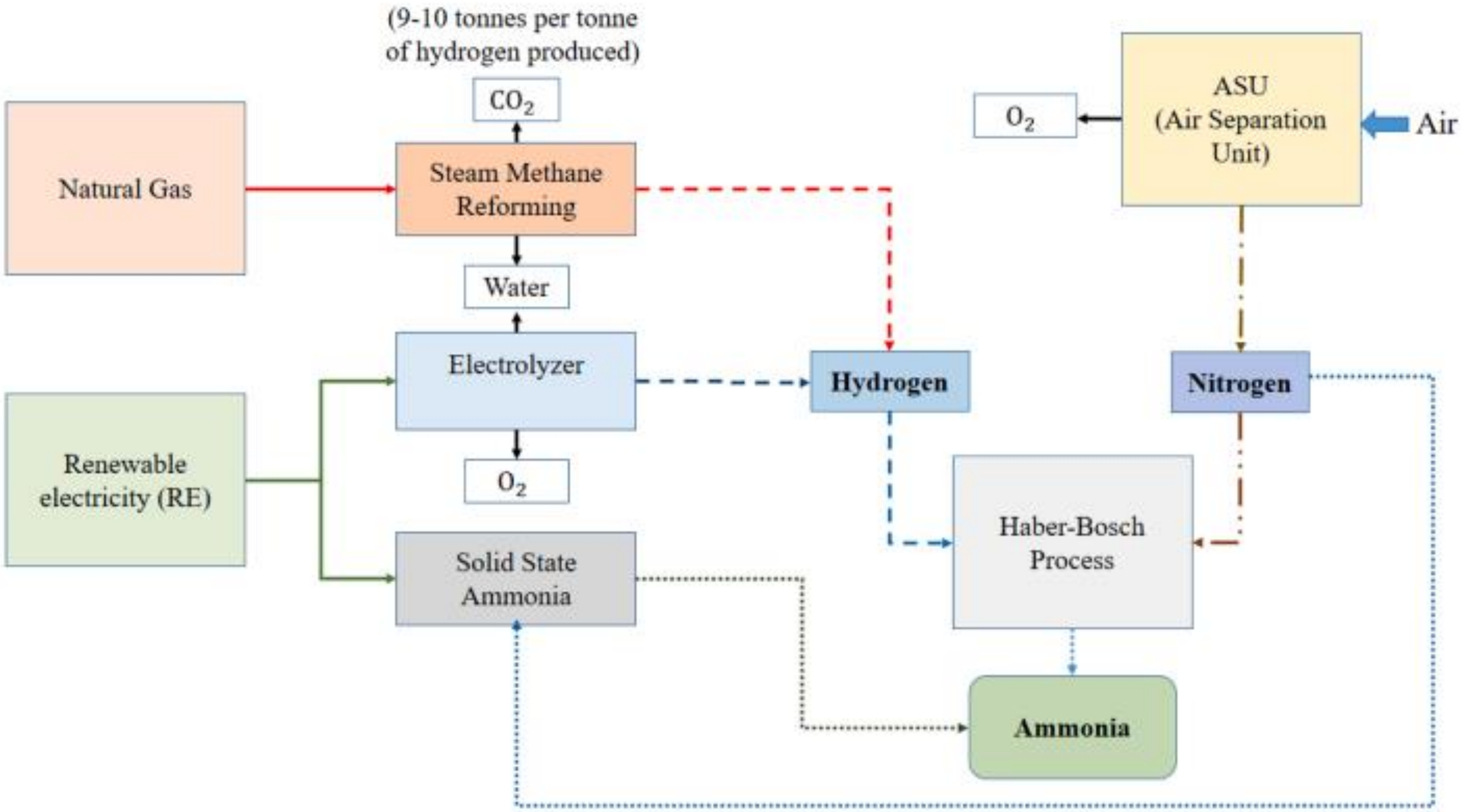
Ancak, gemi motorları yenilenebilir enerji olan amonyakla çalışmak için hala az miktarda pilot yakıta ihtiyaç vardır Bu nedenle pilot yakıtın da karbon sıfır olması önemlidir (Ash, 2019).



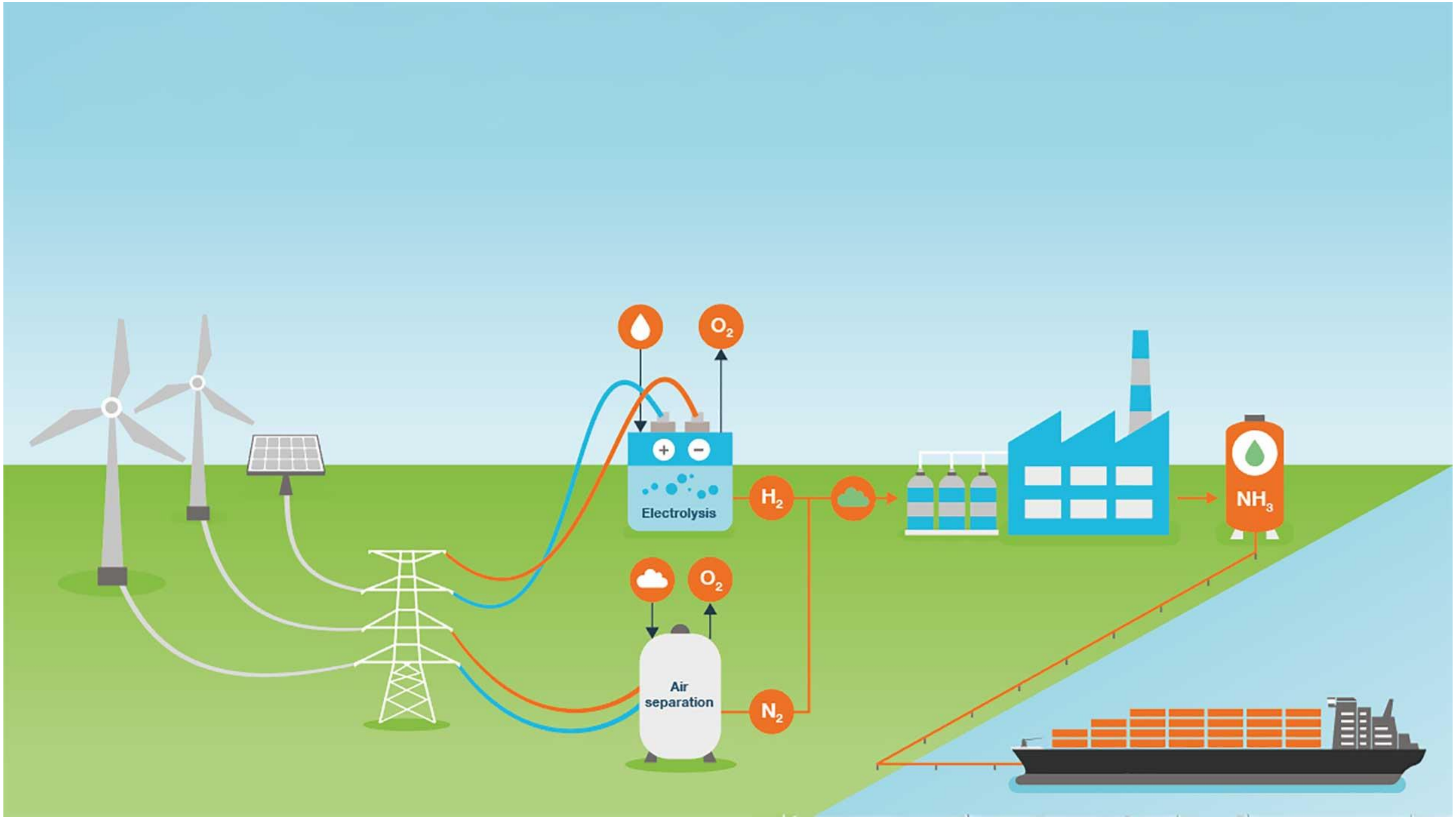
AMONYAK

AMONYAK ÜRETİMİ




(9-10 tonnes per tonne of hydrogen produced)
CO2
Natural Gas
Steam Methane Reforming
Water
Electrolyzer
O2
Renewable electricity (RE)
Solid State Ammonia
Hydrogen
ASU (Air Separation Unit)
O2
Air
Nitrogen
Haber-Bosch Process
Ammonia

AMONYAK



AMONYAK

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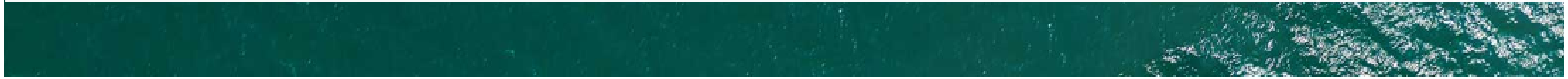


MAN Energy Solutions is developing a fuel-flexible, two-stroke ammonia engine as a key technology in the maritime energy transition

Green ammonia is among several synthetic fuels key to establishing a greener shipping industry in the near future. MAN Energy Solutions aims to have a commercially available two-stroke ammonia engine by as early as 2024, followed by a retrofit package for the gradual rebuild of existing maritime vessels by 2025.

By Nils Lindstrand

AMONYAK

ARTICLE

Marine ammonia engines: working towards deployment in Japan

Julian Atchison May 07, 2024

MAN Energy Solutions has announced one of the first deployments of its ammonia two-stroke engine will take place in Japan. Mitsui E&S will construct the MAN B&W 7S60ME dual-fuel engine, with Imabari Shipbuilding to then install it aboard a Newcastlemax bulk carrier, along with an integrated SCR catalytic converter to treat engine NO_X emissions. The news underscores significant momentum for the deployment of marine ammonia engines, with Wärtsilä, WinGD and Mitsubishi Shipbuilding also engaged in ongoing projects.

Continue Reading

AMONYAK

ARTICLE

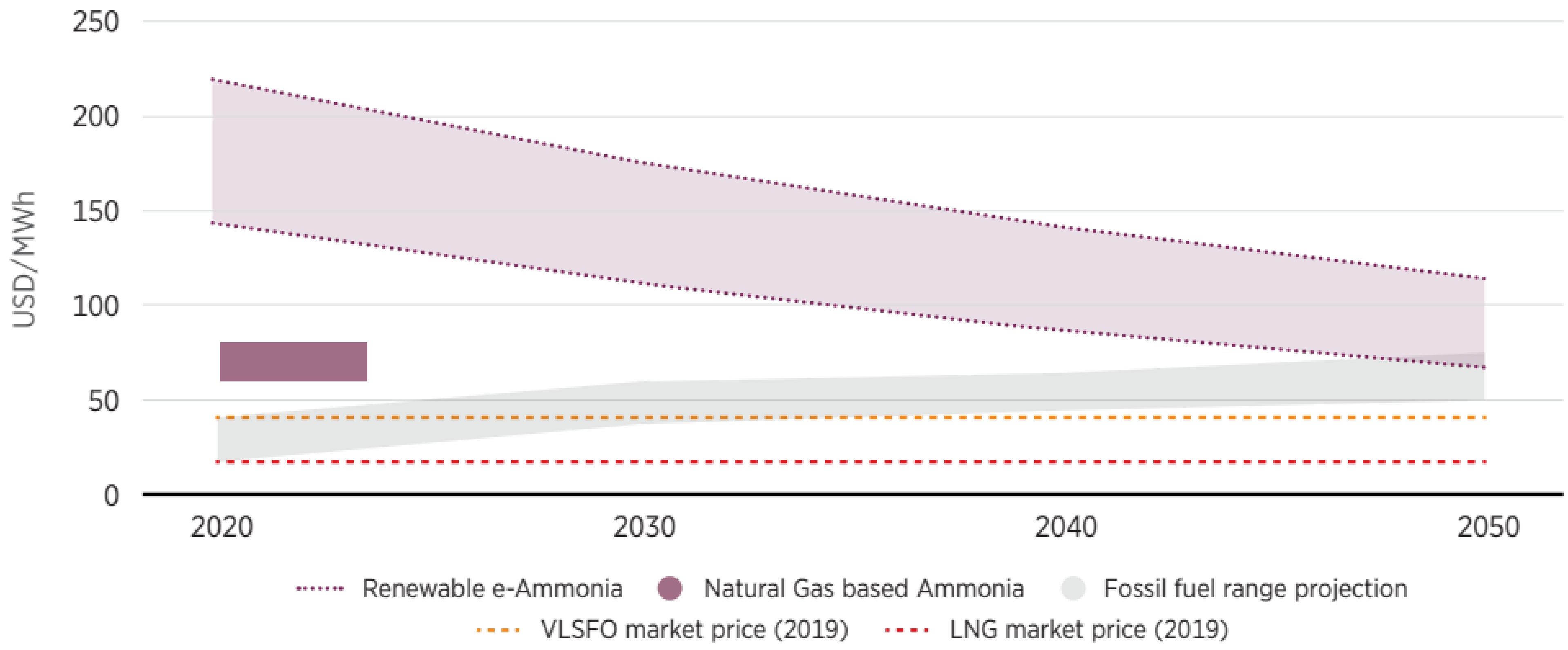
Ammonia-fueled vessels: shipyard orders and new concepts

Geofrey Njovu May 07, 2024

Eastern Pacific Shipping's on-order very large ammonia carriers (VLACs) will be registered in Singapore, thanks to a new partnership with the Maritime and Port Authority. Trafigura has announced the first of its ammonia-fueled, medium gas carriers will be delivered from South Korea in 2027. In Japan, K LINE and MAN are leading a 5-party collaboration to develop ammonia fueled-engines and deploy them in 200,000 dwt bulk carriers. We also explore ammonia-fueled Aframaxes in Malaysia, a concept study for a large-volume, coastal ammonia carrier in Japan, and a new salmon fishing vessel design in Norway.

AMONYAK

Figure 24 **Ammonia cost projections**



AKADEMİK ÇALIŞMALAR

HATIRLAYALIM – YAKIT ÖZELLİKLERİ

Fuel type	LHV (MJ/kg)	Volumetric energy density (GJ/m³)	Storage pressure (bar)	Storage temperature (°C)
MGO	42.7	36.6	1	120
LNG	50	23.4	1	-162
Methanol	19.9	15.8	1	20
Liquid ammonia	18.6	12.7	1	-34
			8.6	20
Liquid H_2	120	8.5	1	-253
Compressed H_2	120	7.5	700	20

Note: GJ = gigajoules; m^3 = cubic metres.

Source: IRENA (2019a)

HATIRLAYALIM – YAKIT ÖZELLİKLERİ

Key fuel properties of alternative marine fuels (DNVGL, 2019b; Xing et al., 2021b).

Fuel	Chemical formula	Density at 15 °C (kgm^{-3})	Cetane number	Boiling point °C	Auto-ignition temperature in air °C	Flammability limits in air vol%	Toxicity	CO_2[a]	SO_x[a]	NO_x[a]	PM[a]
LSHFO	C_8–C_{25}	975–1010	>20	>180	230	0.6–7.5	–	High	Medium	High	Medium
MDO	C_{10}–C_{15}	796–841	>35	>180	210	0.6–7.5	–	High	Low	High	Low
NG	CH_4	0.78	130[b]	−162	540	5.0–15.0	NT	Medium	Low	Medium	Low
METH	CH_3OH	792	<5	65	464	6.7–36	LAT	Medium	Low	Medium	Low
HYD	H_2	0.09	>130[b]	−253	585	4.0–75.0	NT	Low	Low	High	Low
AMMO	NH_3	0.73	120[b]	−33	651	15.0–28.0	HT	Low	Low	High	Low
HVO	C_{15}–C_{18}	770–790	>70	>180	204	0.6–7.5	NT	High	Low	High	Low
ELEC	N/A	N/A	N/A	N/A	N/A	N/A	–	–	–	–	–

Note-.

[a] Combustion emissions in ICE; LSHFO: low sulfur HFO; MDO: marine diesel oil; NG: natural gas; METH: methanol; HYD: hydrogen; HVO: Hydrotreated vegetable oil (advanced biodiesel); AMMO: ammonia; ELEC; electricity; N/A: not applicable; NT: Not toxic; LAT: Low acute toxicity; HT: Highly toxic.

[b] Octane number.

HATIRLAYALIM – YAKIT ÖZELLİKLERİ

Status of viability for different alternative fuels (DNVGL, 2019a, b).

Criteria	LNG	Methanol	HVO	Ammonia[c]	Hydrogen[c]	Fully electric[c]
Energy density	4	4	5	3	2	1
Technological maturity	4	3	5	2	2	3
Local emissions	4	4	2	3	5	5
GHG emissions	2[b]	2[b]	4	5	5	5
Energy cost	5	3	2	1	1	V[d]
Capital cost	4	4	5	4	1	5
Converter storage	3	4	5	4	1	1
Bunkering availability	4	3	1	2	1	2
Commercial readiness[a]	5	4	3	2	1	V
Flammability	5	4	5	2	1	5
Toxicity	5	3	5	1	5	5
Regulations and guidelines	5	4	5	3	1	4
Global production capacity and locations	5	3	2	3	3	1

1-5: status rating with 1 being extremely poor and 5 being excellent.

V: varies.

e. Needs to be evaluated case-by-case. Not applicable for deep-sea shipping.

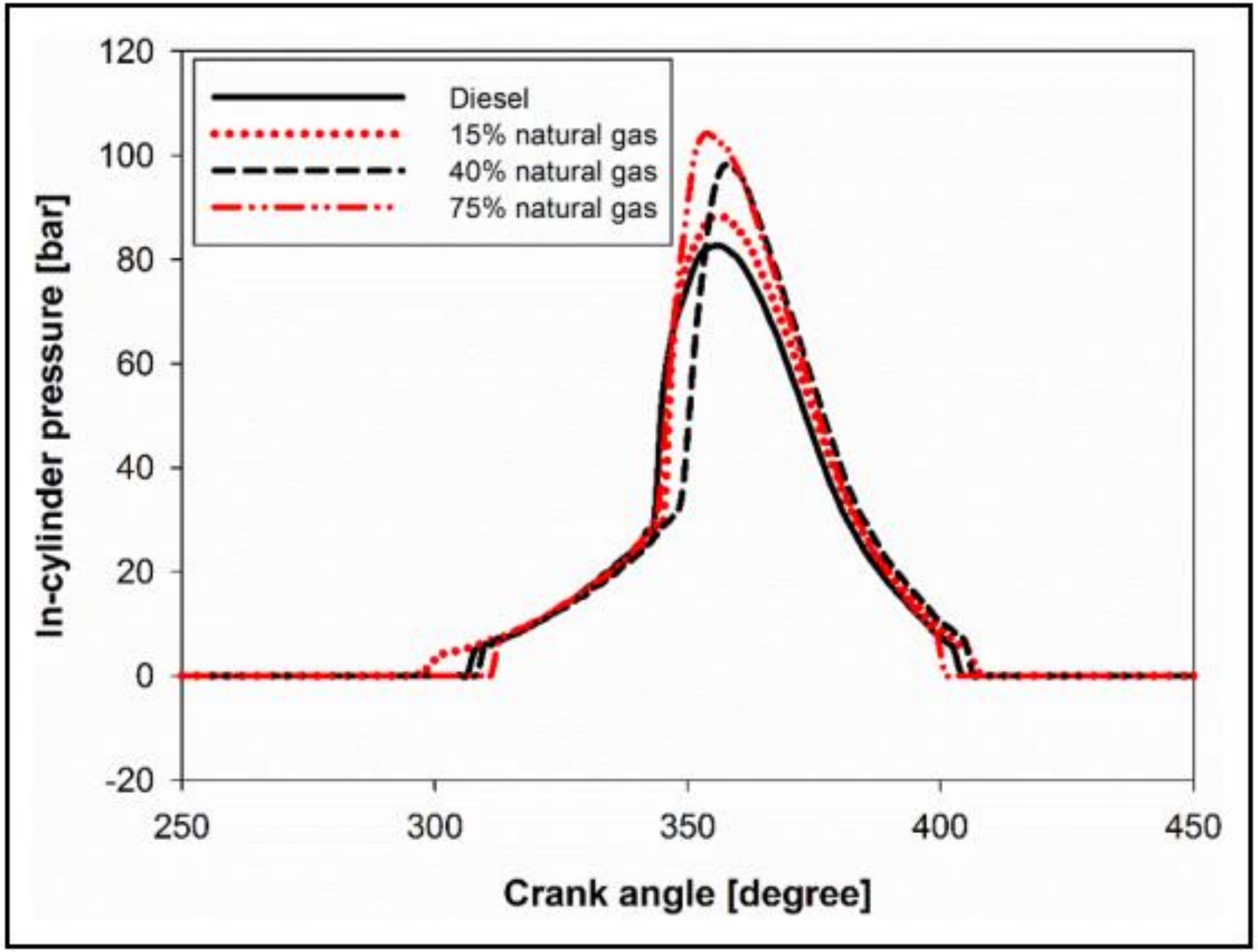
[a] Taking into account maturity and availability of technology and fuel.

[b] GHG benefits for LNG and methanol will proportionally increase with the fraction of corresponding bio- or synthetic energy carrier used as drop-in fuel.

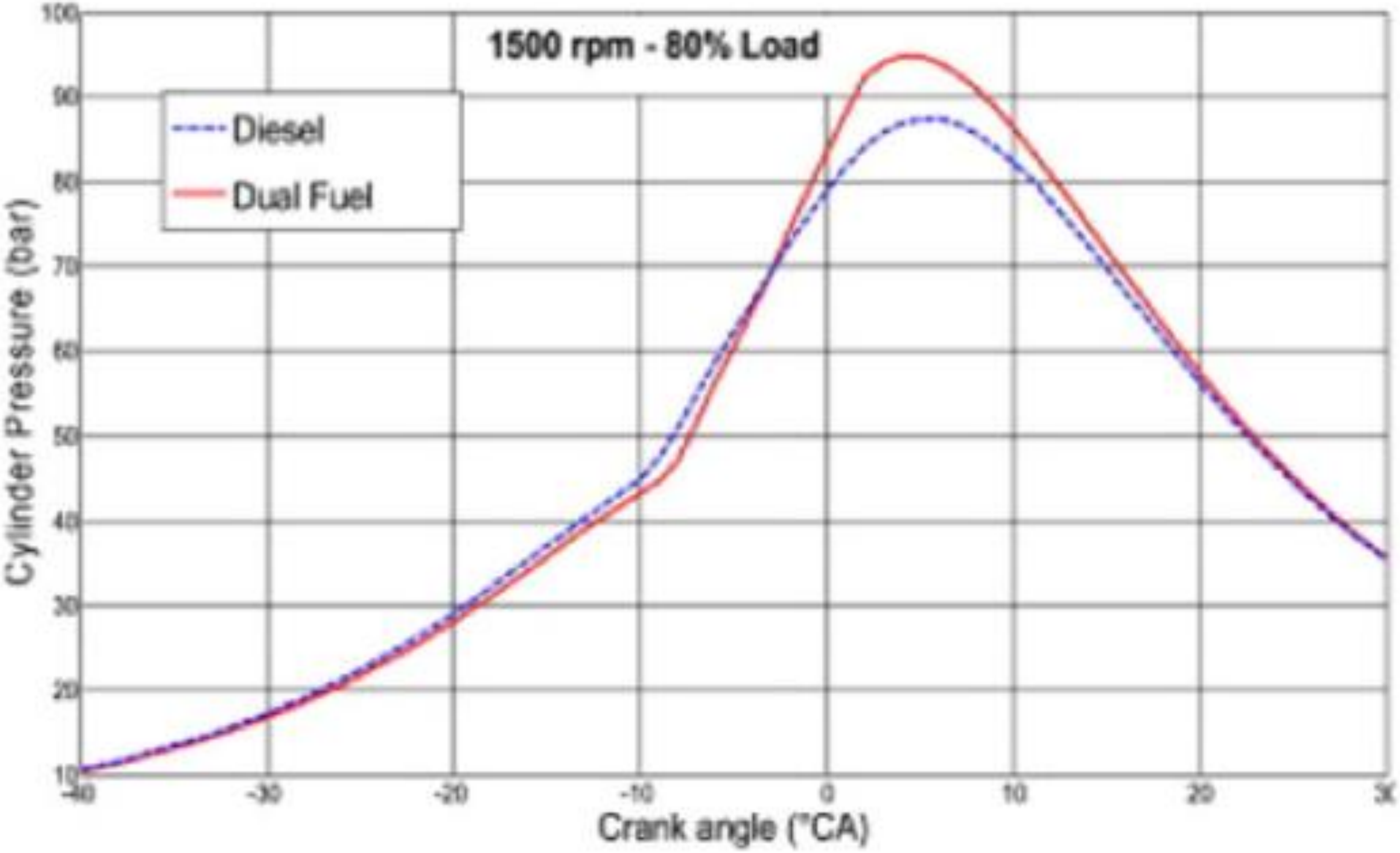
[c] Only from renewable energy sources.

[d] Large regional variations.

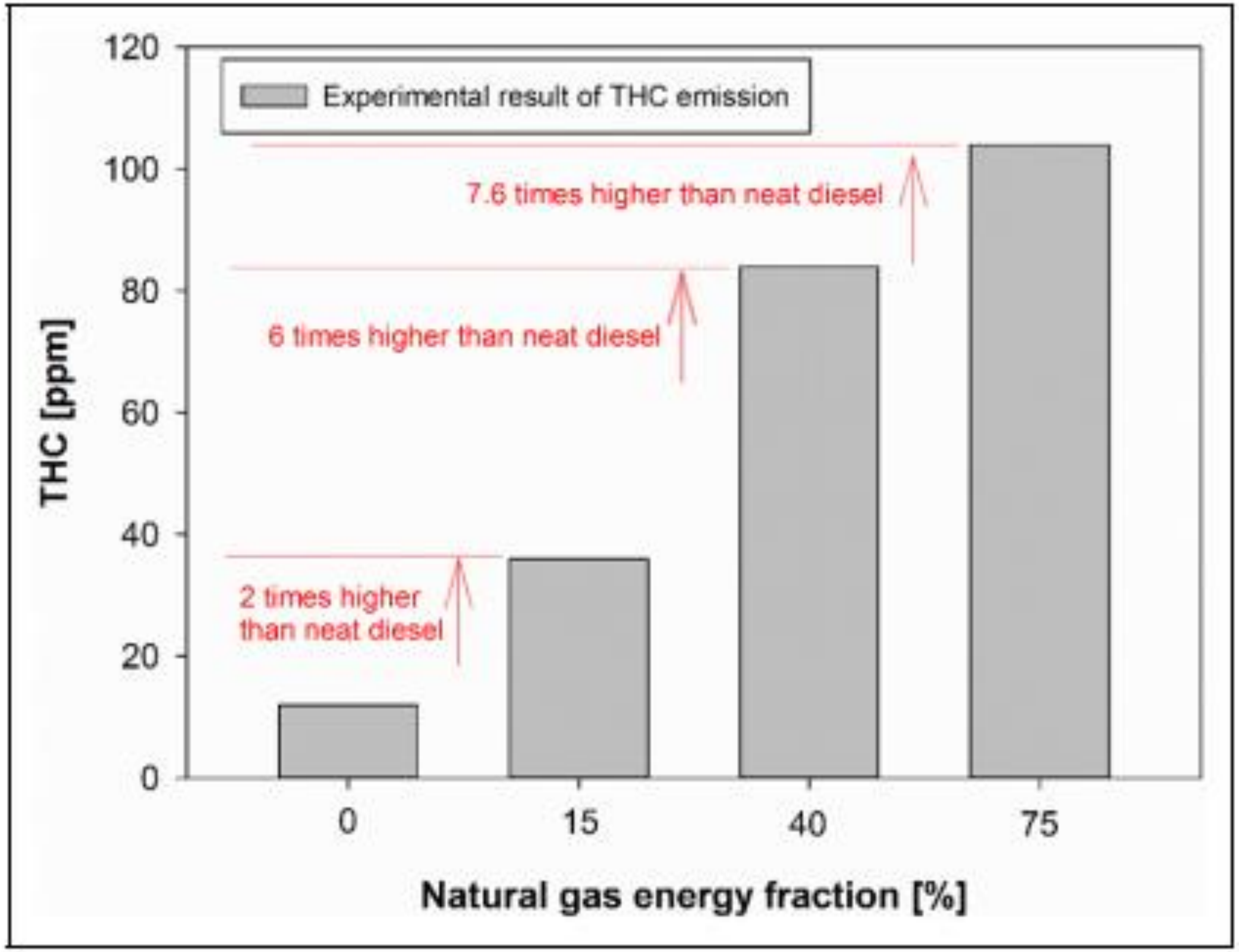
DOĞALGAZ – SİLİNDİR İÇİ BASINÇ



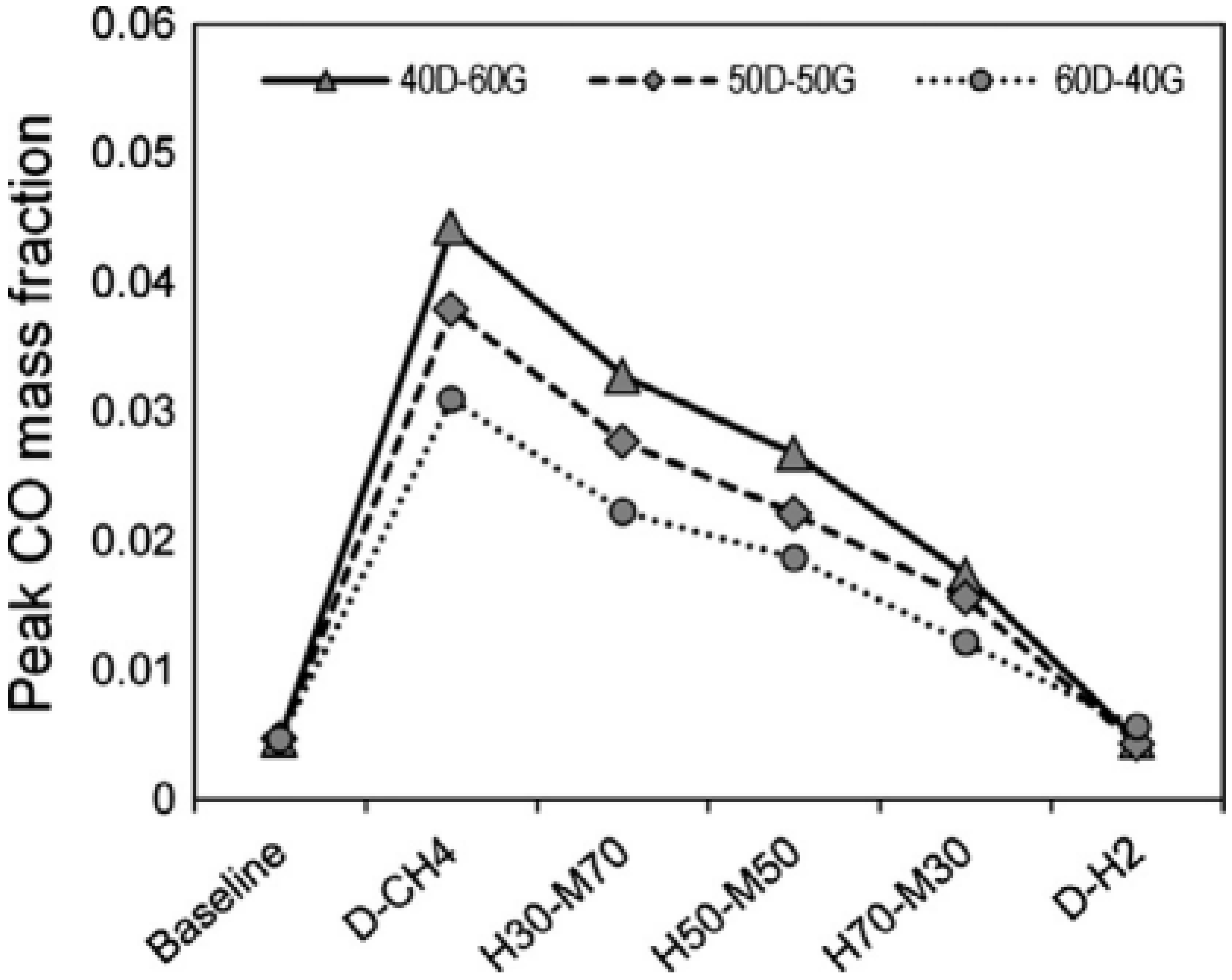
DOĞALGAZ – SİLİNDİR İÇİ BASINÇ



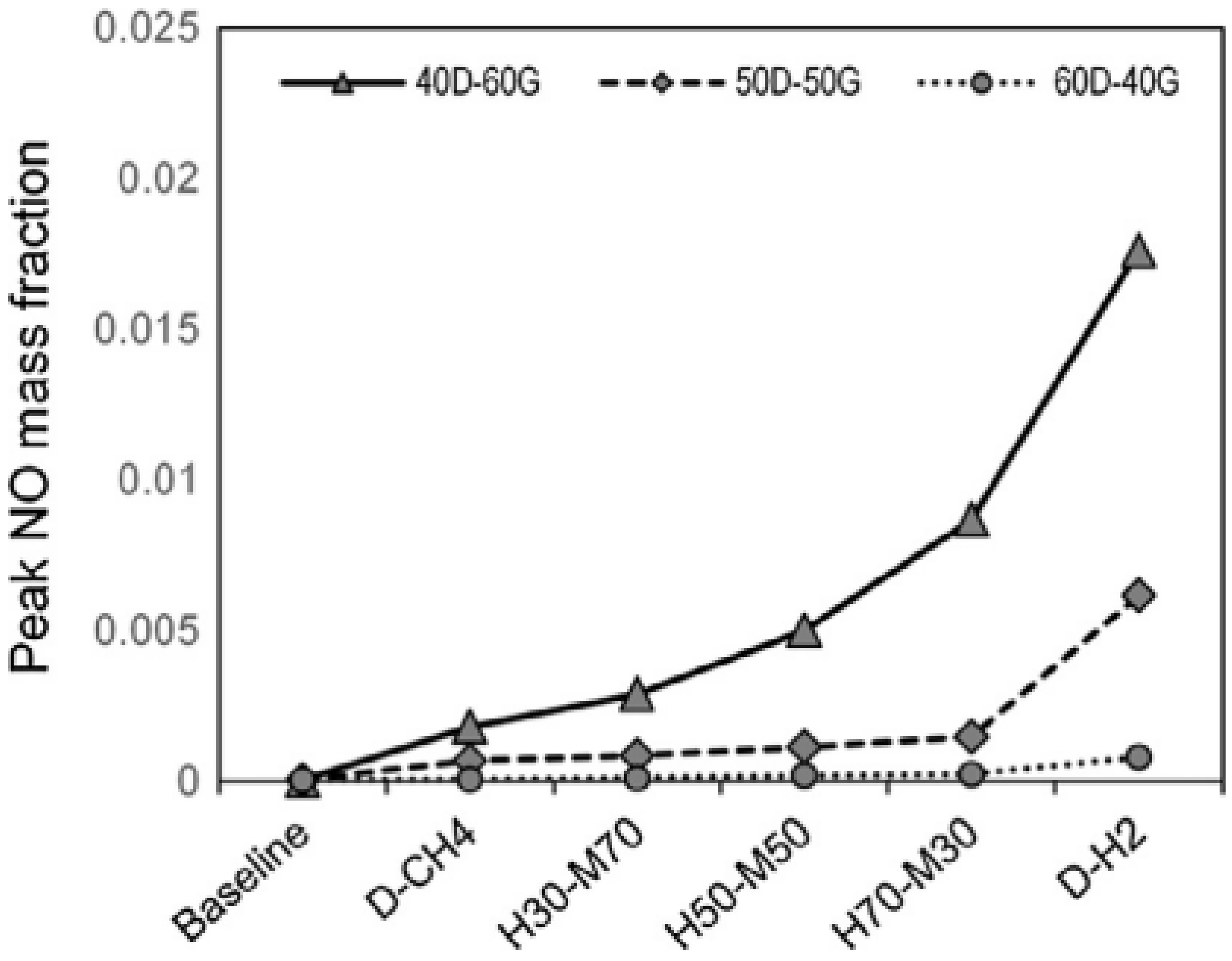
DOĞALGAZ – HC EMİSYONLARI



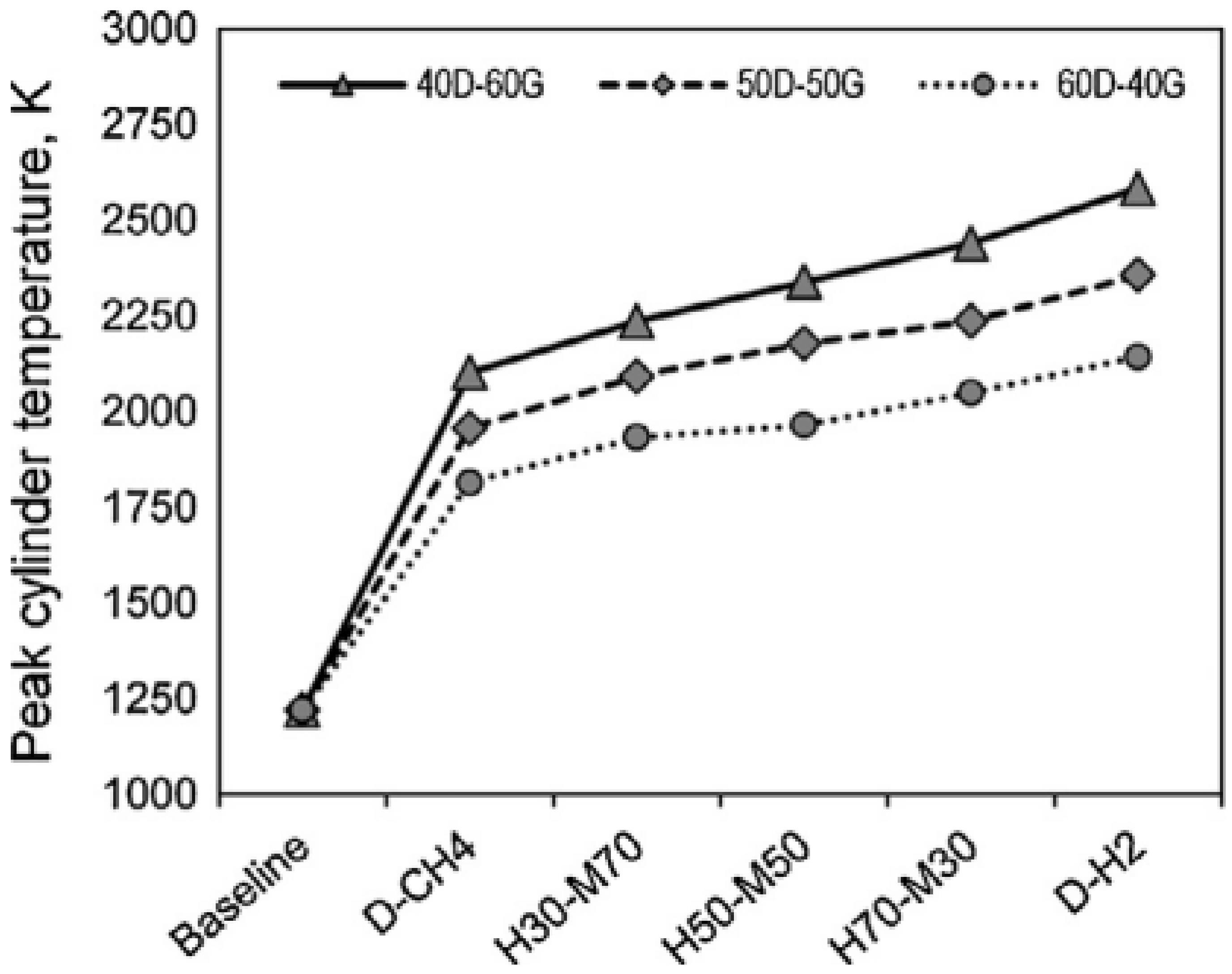
DOĞALGAZ, HİDROJEN – KARBONMONOKSİT EMİSYONLARI



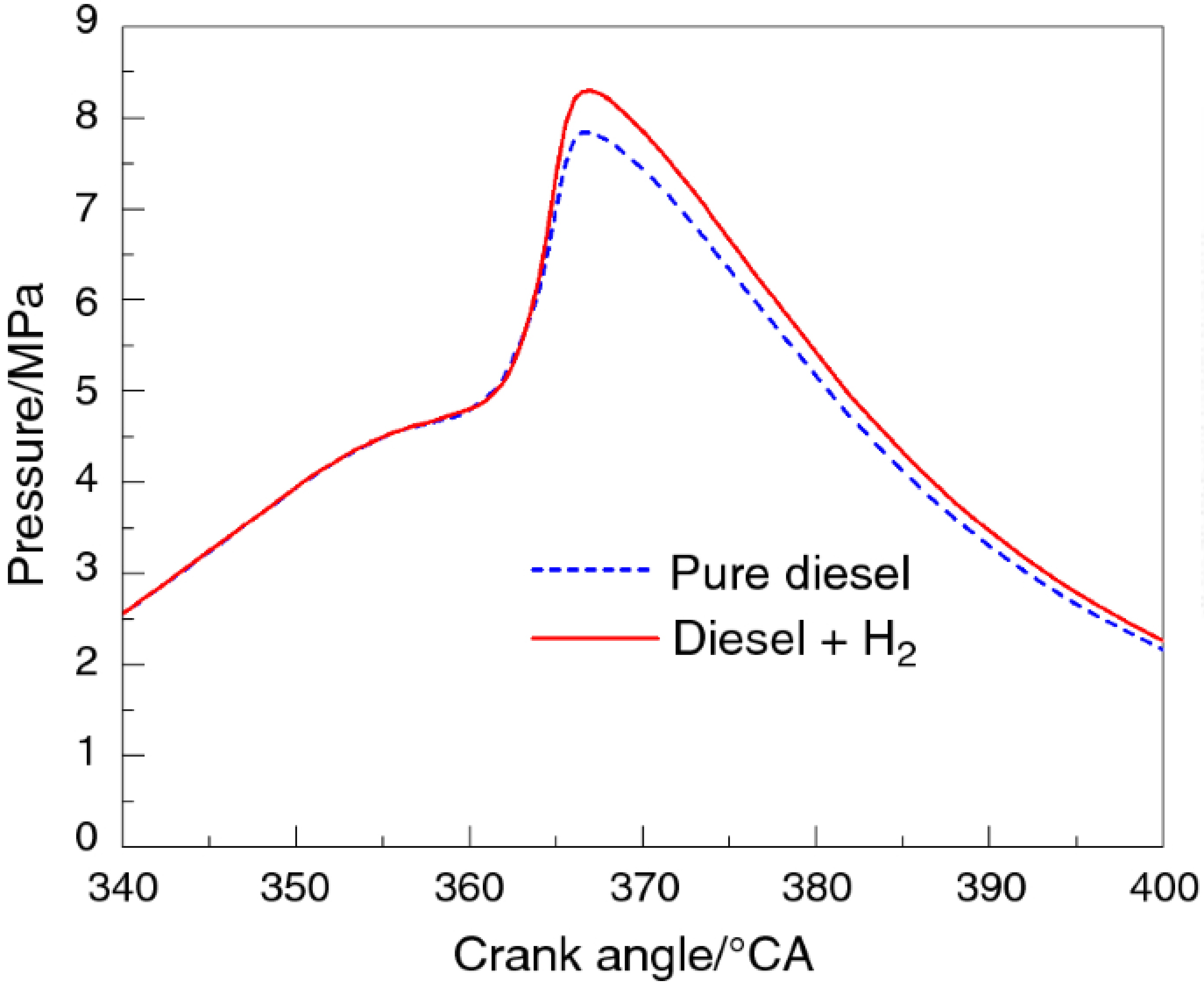
DOĞALGAZ, HİDROJEN – KARBONMONOKSİT EMİSYONLARI

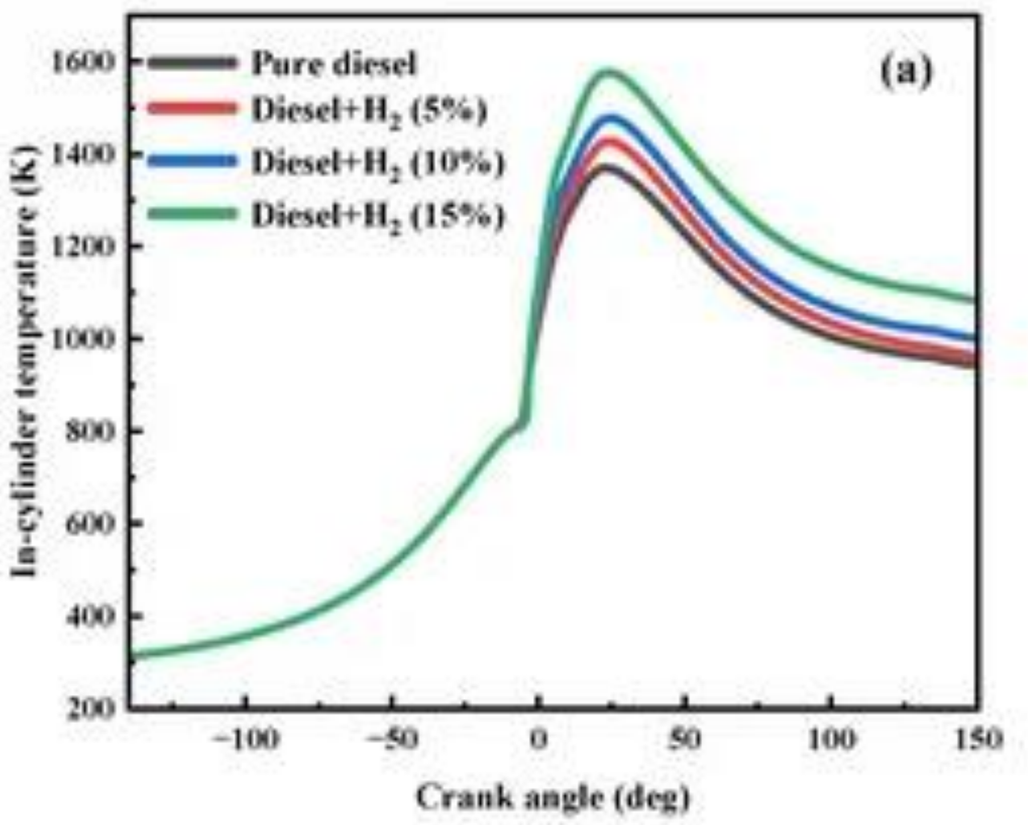


DOĞALGAZ, HİDROJEN – KARBONMONOKSİT EMİSYONLARI

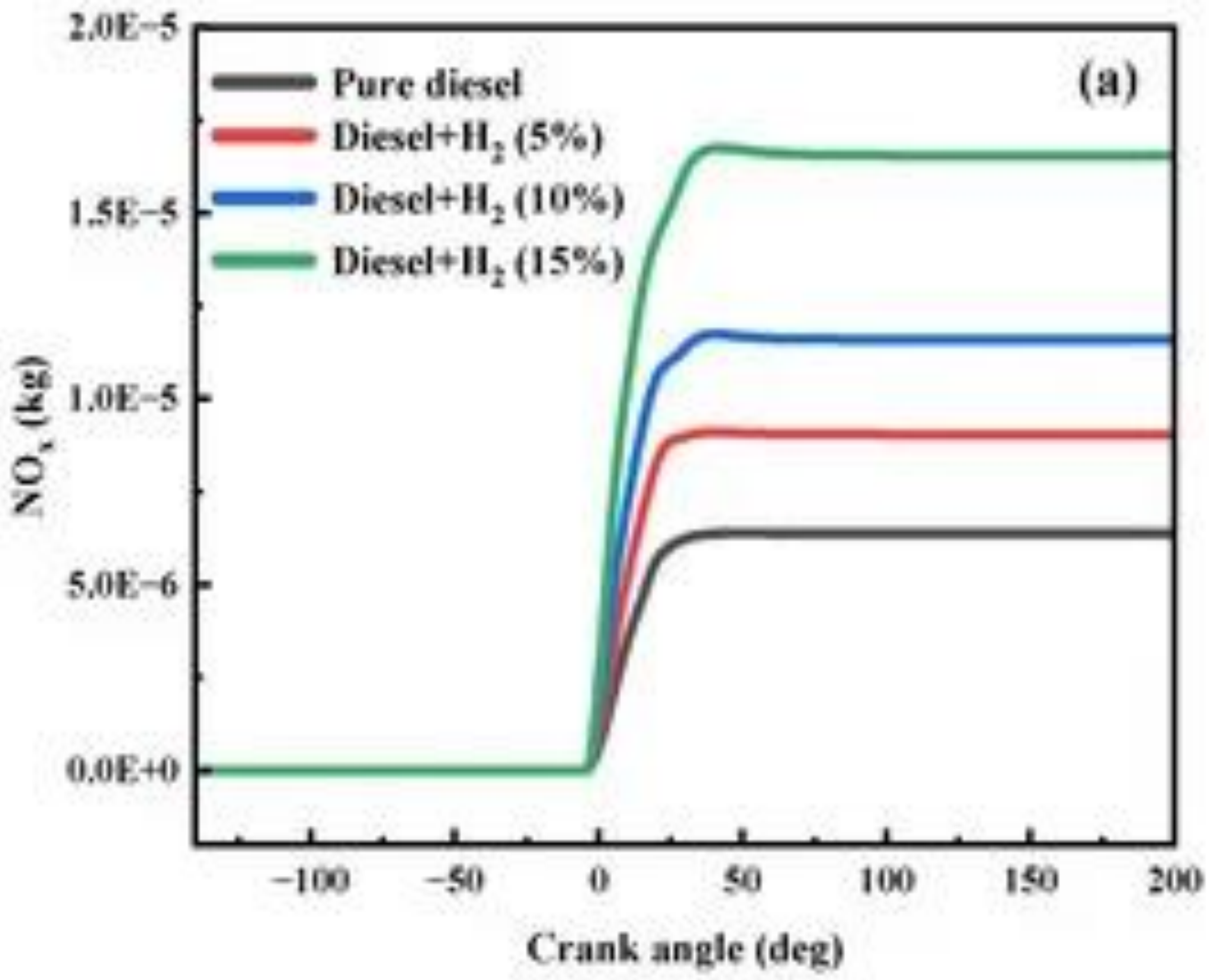


HİDROJEN – SİLİNDİR İÇİ BASINÇ





HİDROJEN – NO EMİSYONLARI



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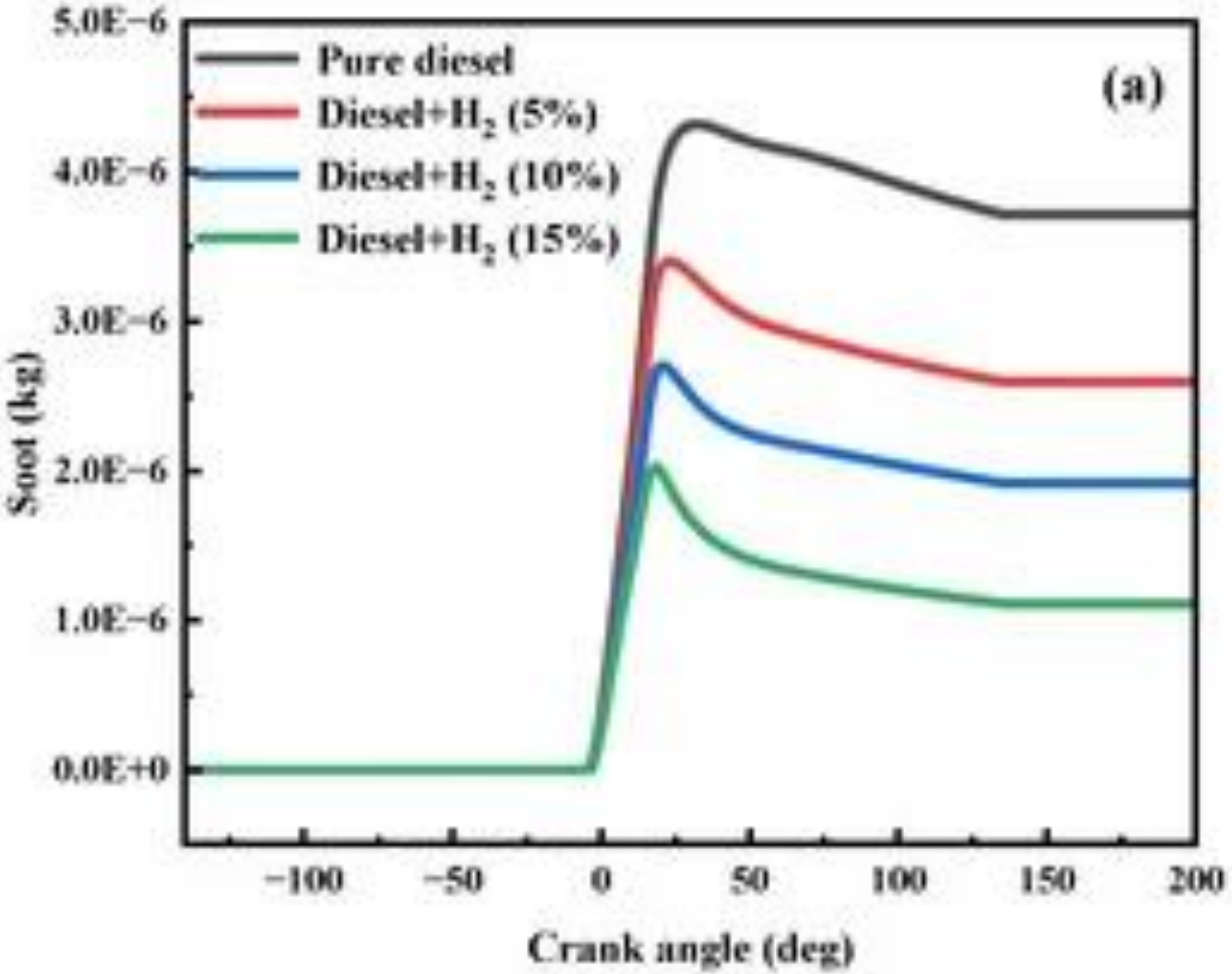
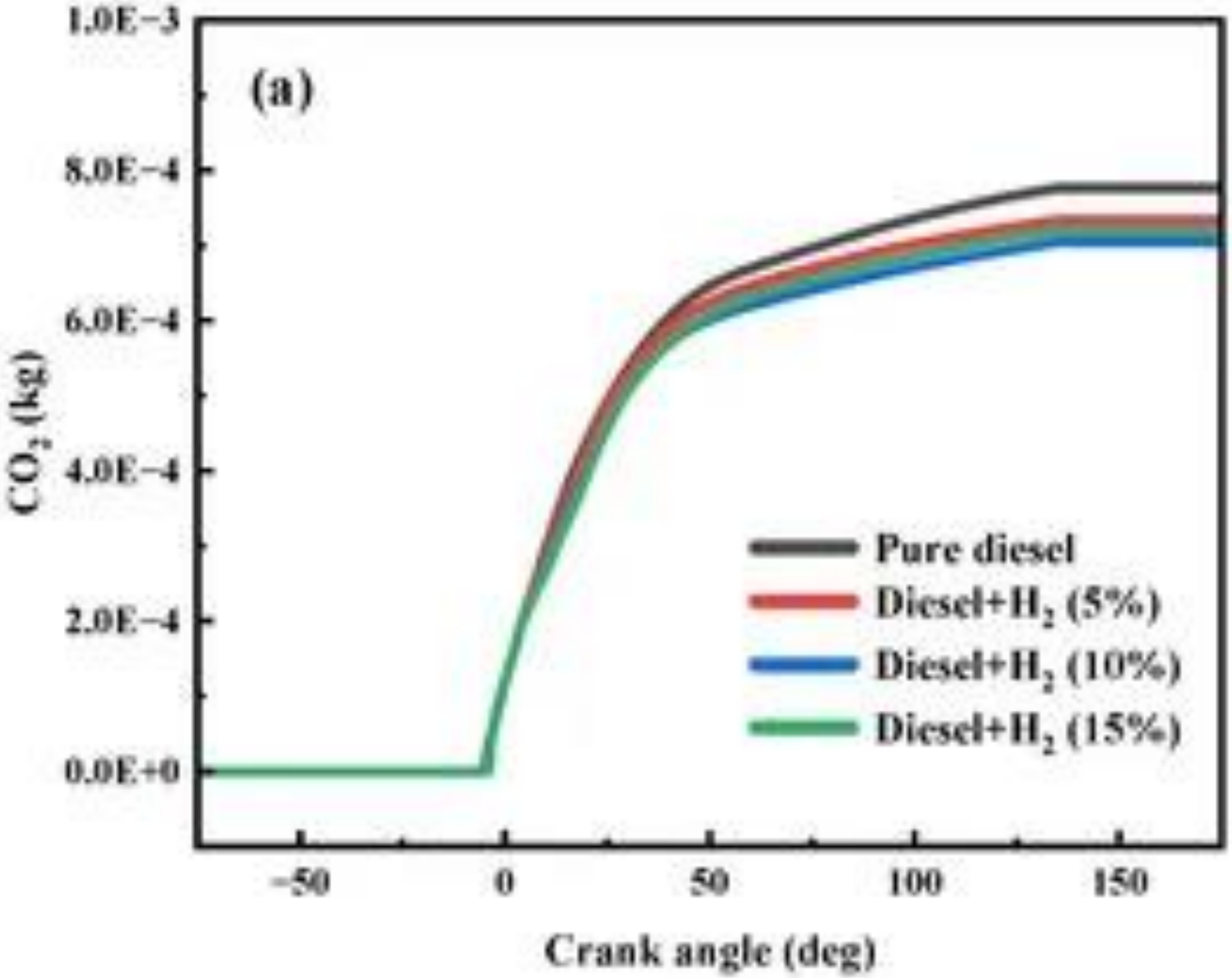
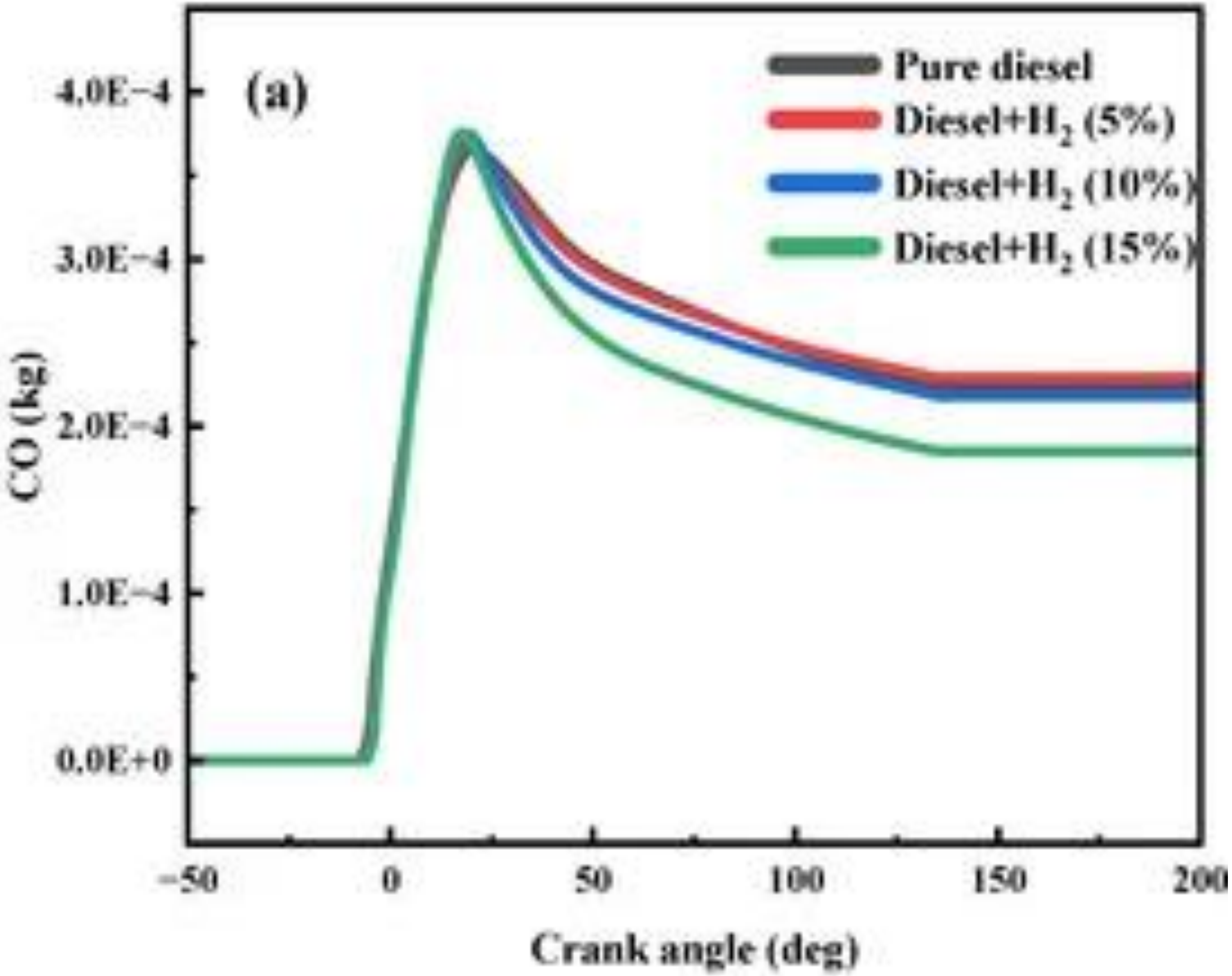


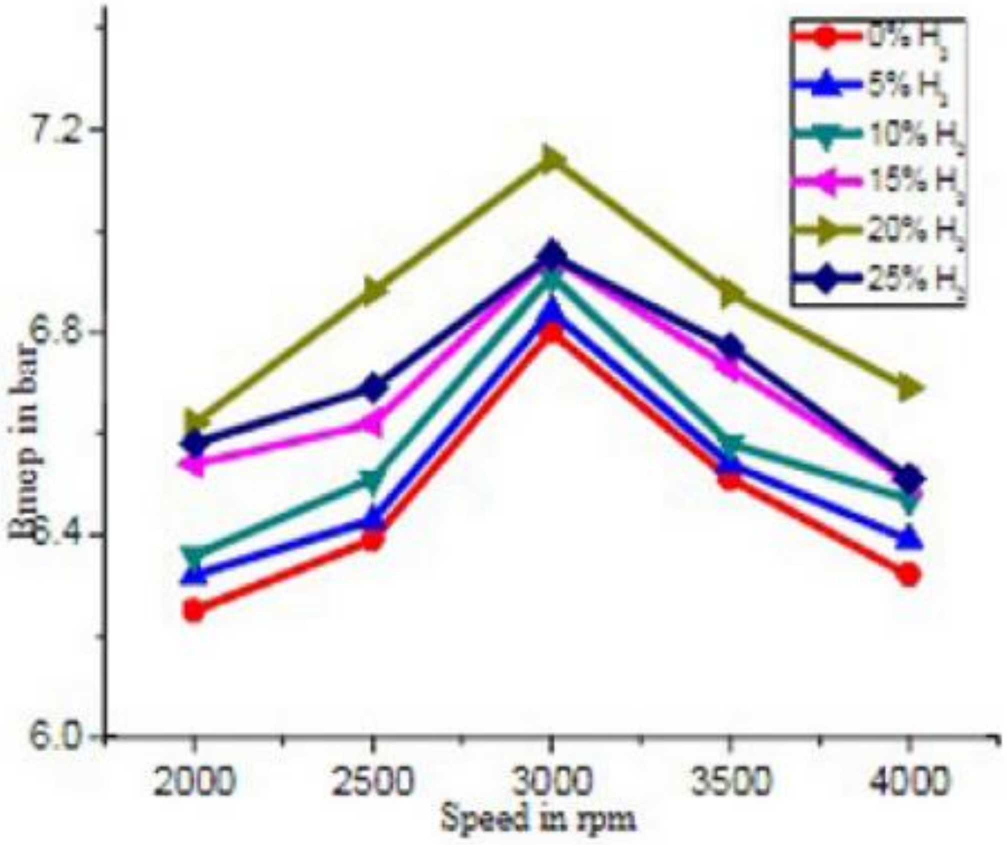
HİDROJEN – KARBONDİOKSİT EMİSYONLARI

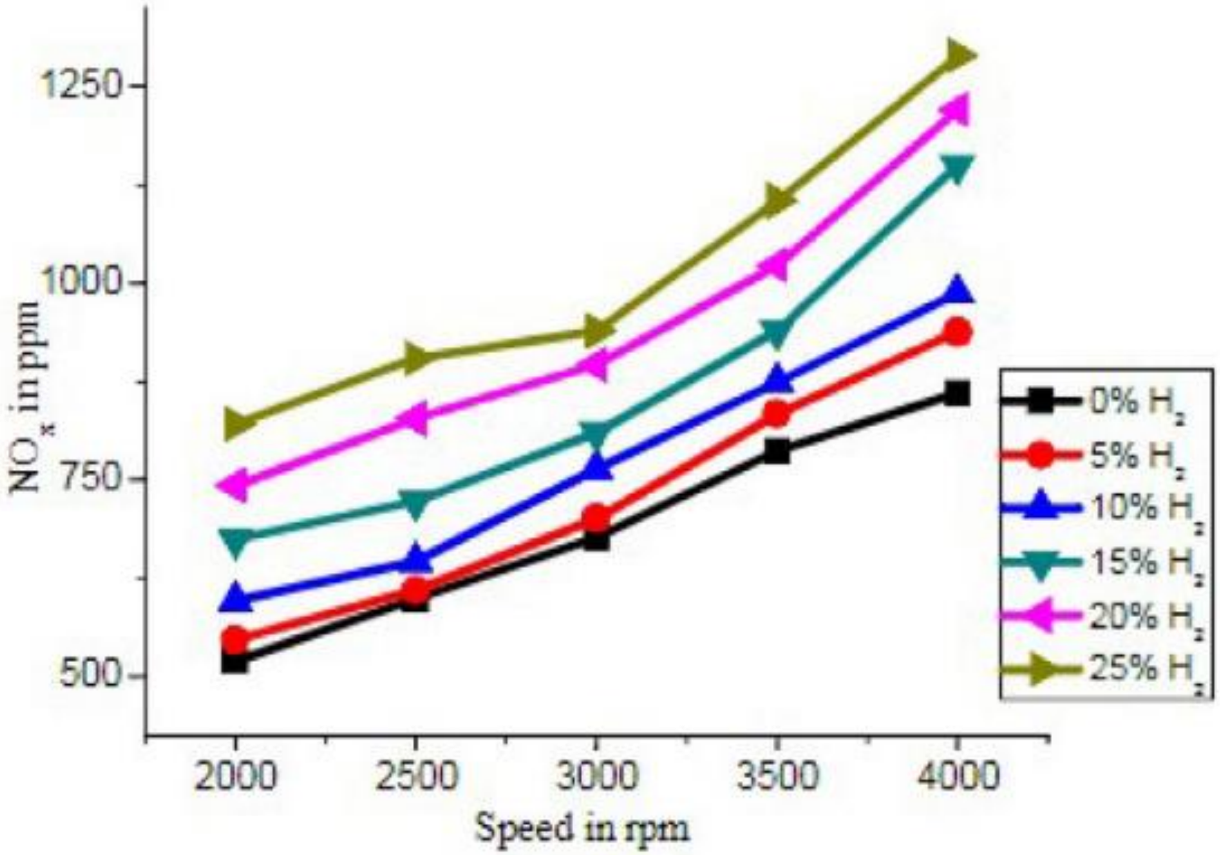


HİDROJEN – KARBONMAONOKSİT EMİSYONLARI

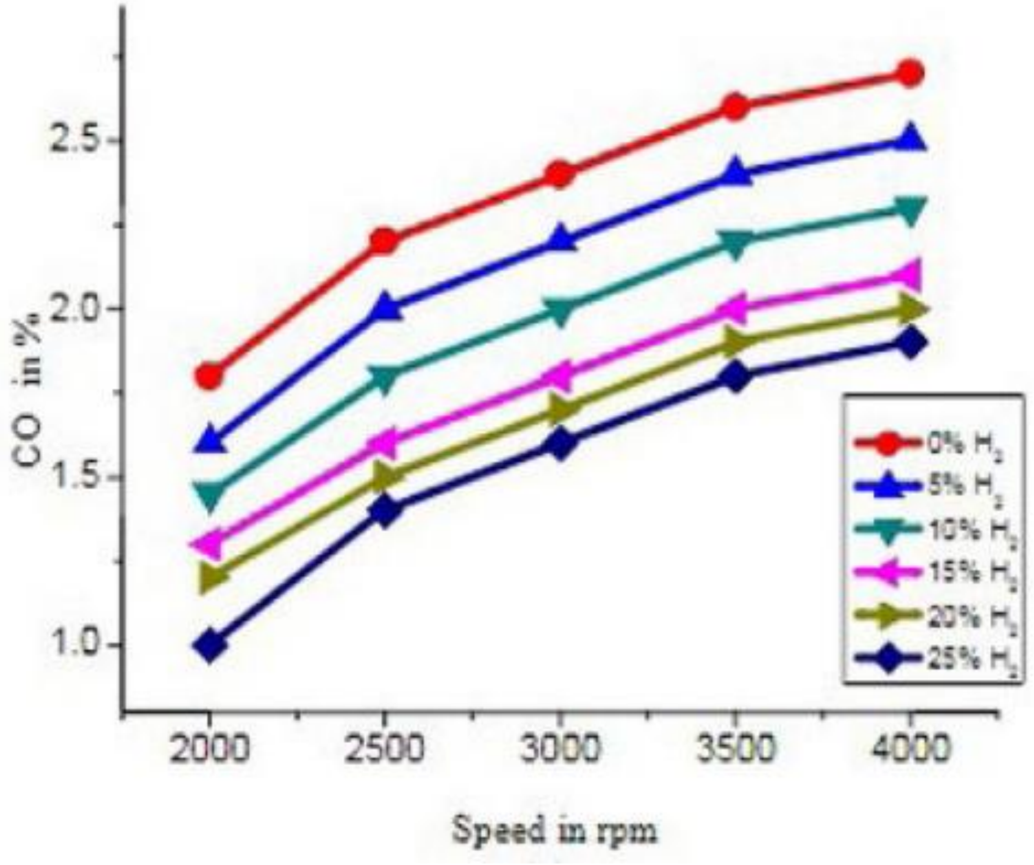


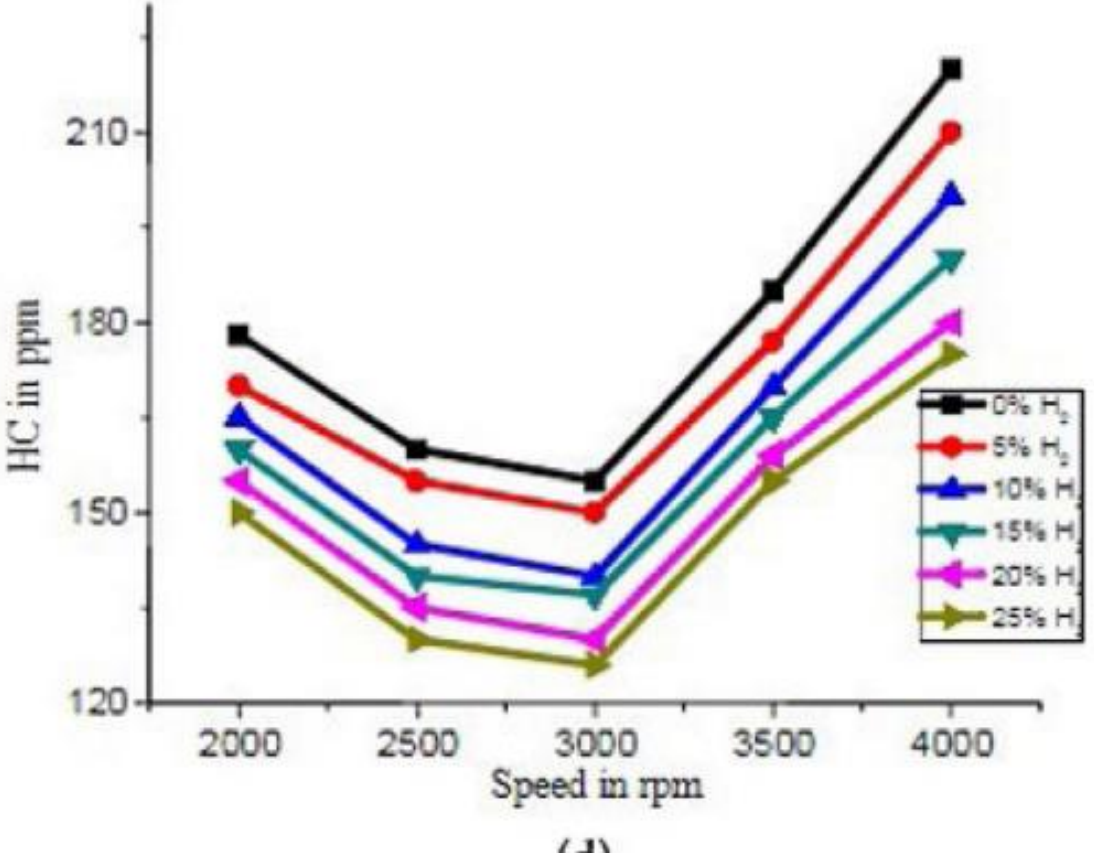
HİDROJEN


0% H2
5% H2
10% H2
15% H2
20% H2
25% H2
7.2
6.8
6.4
6.0
Bmep in bar
2000
2500
3000
3500
4000
Speed in rpm

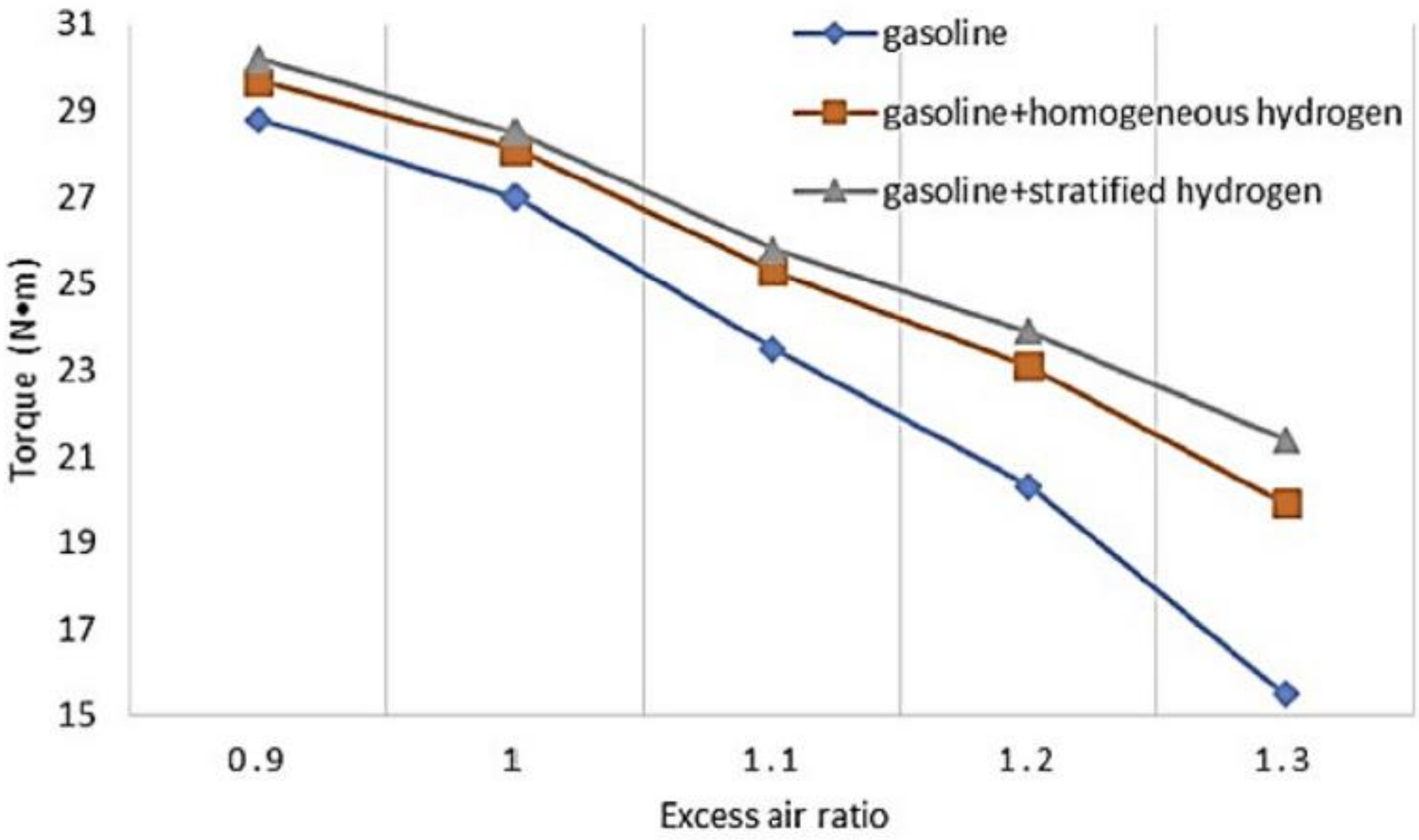

1250
1000
750
500
NOx in ppm
0% H2
5% H2
10% H2
15% H2
20% H2
25% H2
2000
2500
3000
3500
4000
Speed in rpm

HİDROJEN


CO in %
2.5
2.0
1.5
1.0
2000
2500
3000
3500
4000
Speed in rpm
0% H2
5% H2
10% H2
15% H2
20% H2
25% H2

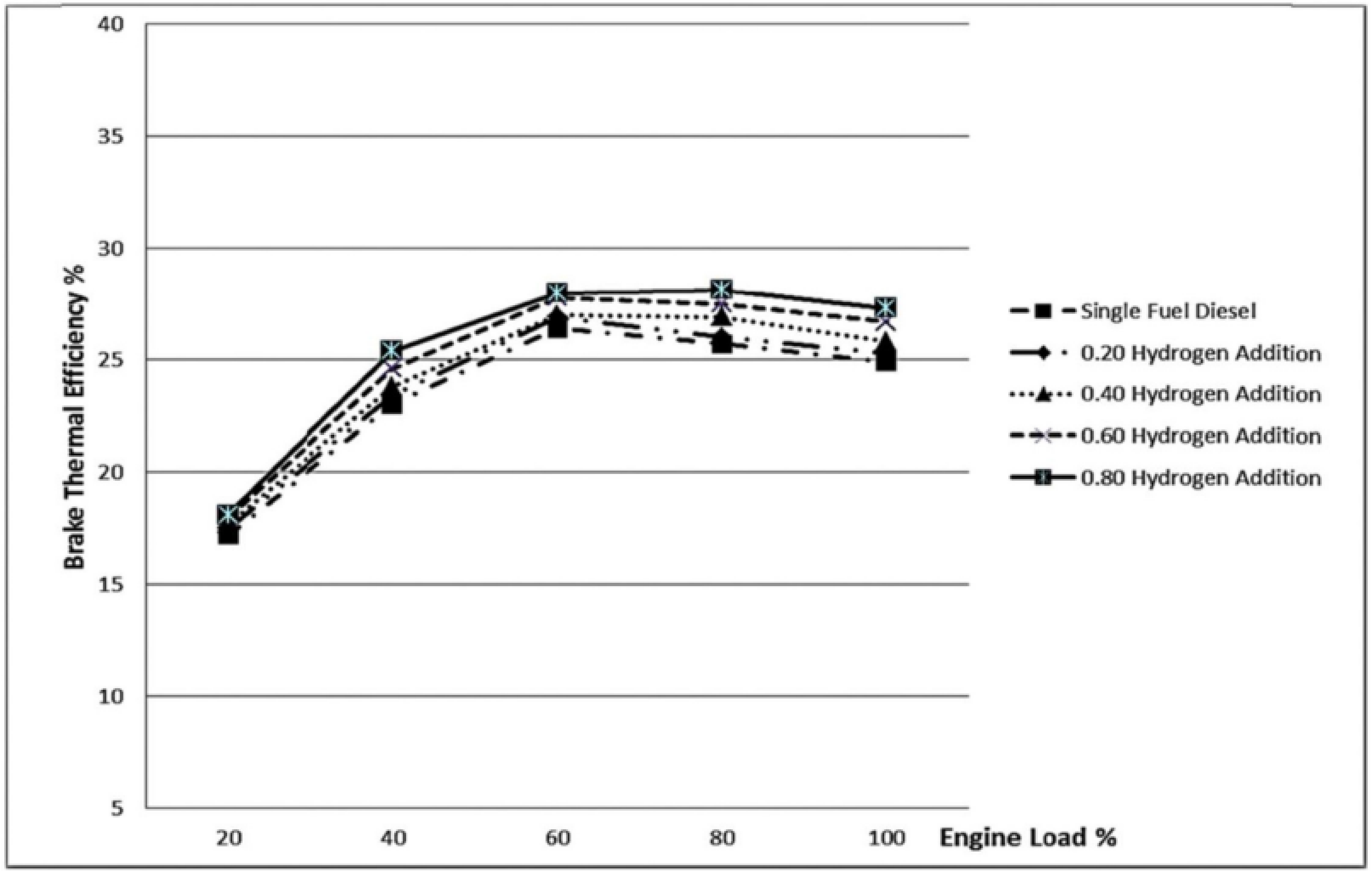

HC in ppm
210
180
150
120
2000
2500
3000
3500
4000
Speed in rpm
0% H2
5% H2
10% H2
15% H2
20% H2
25% H2

HİDROJEN



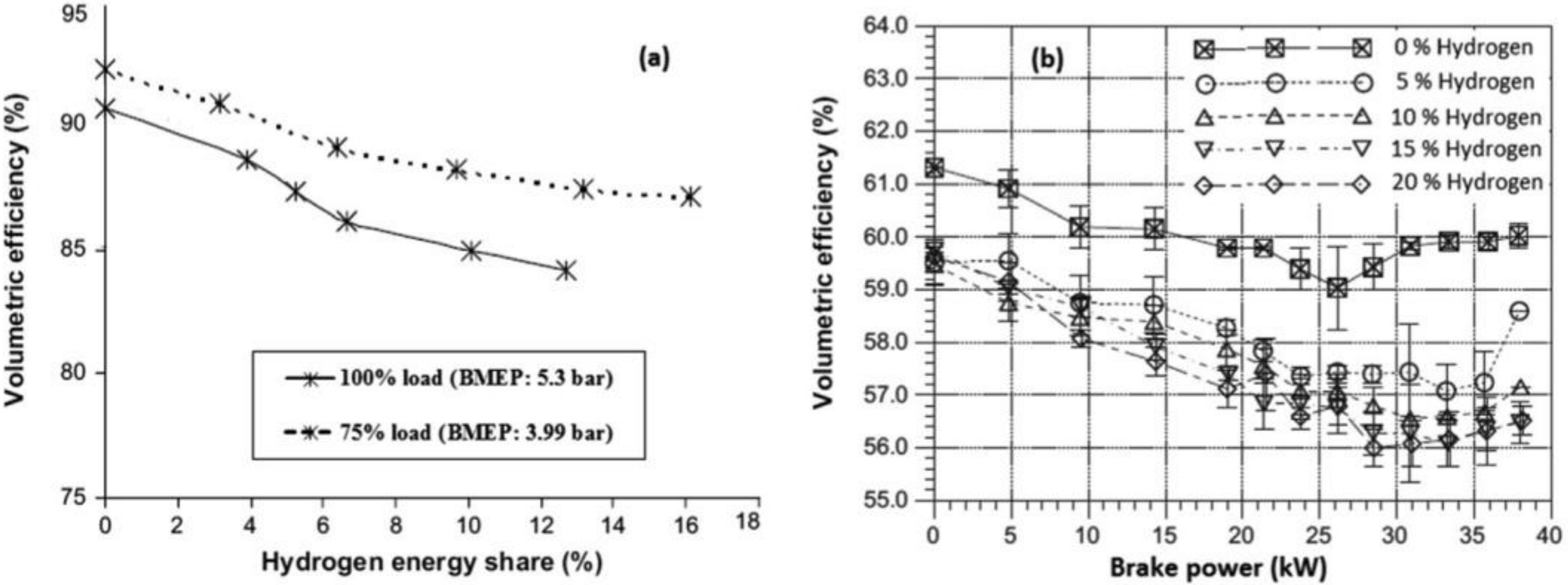
31
29
27
25
23
21
19
17
15
Torque (N•m)
gasoline
gasoline+homogeneous hydrogen
gasoline+stratified hydrogen
0.9
1
1.1
1.2
1.3
Excess air ratio

HİDROJEN



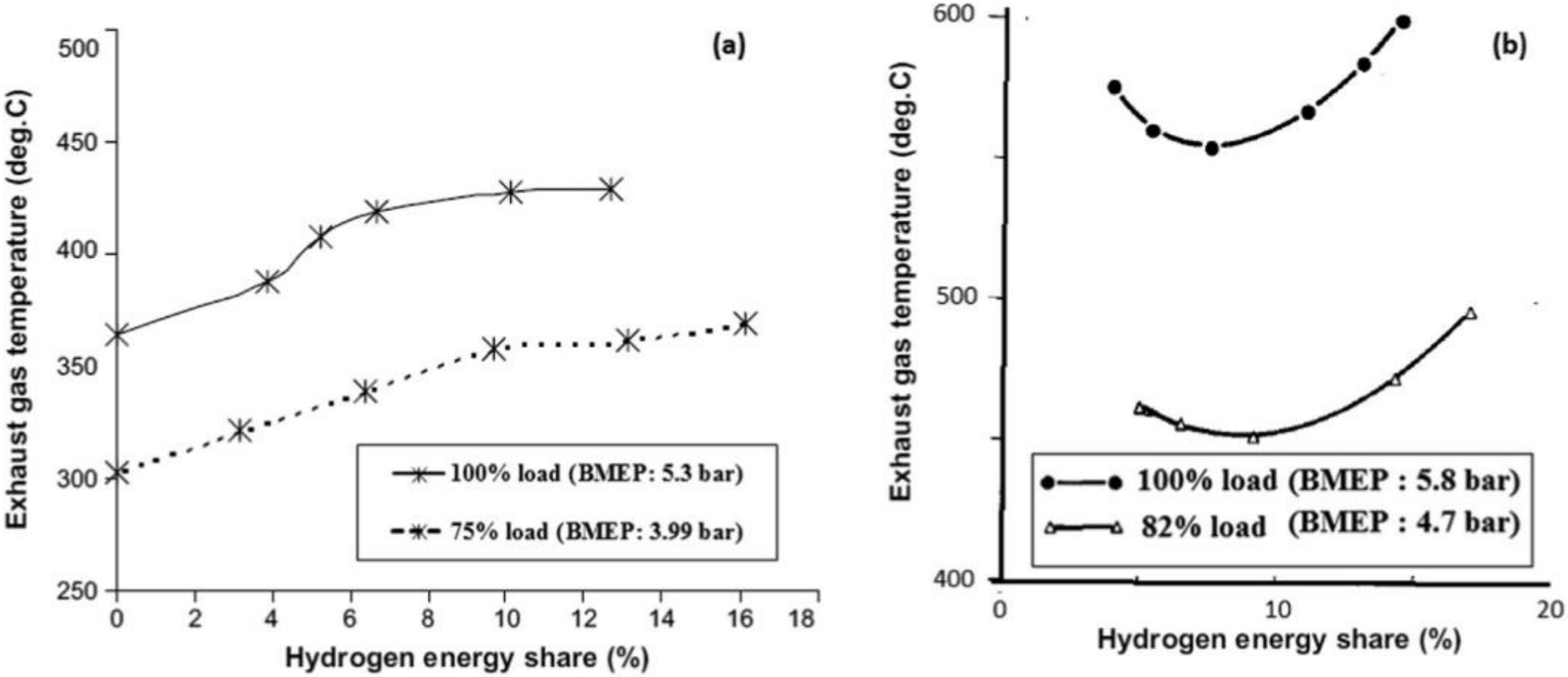
Brake Thermal Efficiency %
40
35
30
25
20
15
10
5
20
40
60
80
100
Engine Load %
Single Fuel Diesel
0.20 Hydrogen Addition
0.40 Hydrogen Addition
0.60 Hydrogen Addition
0.80 Hydrogen Addition

HİDROJEN

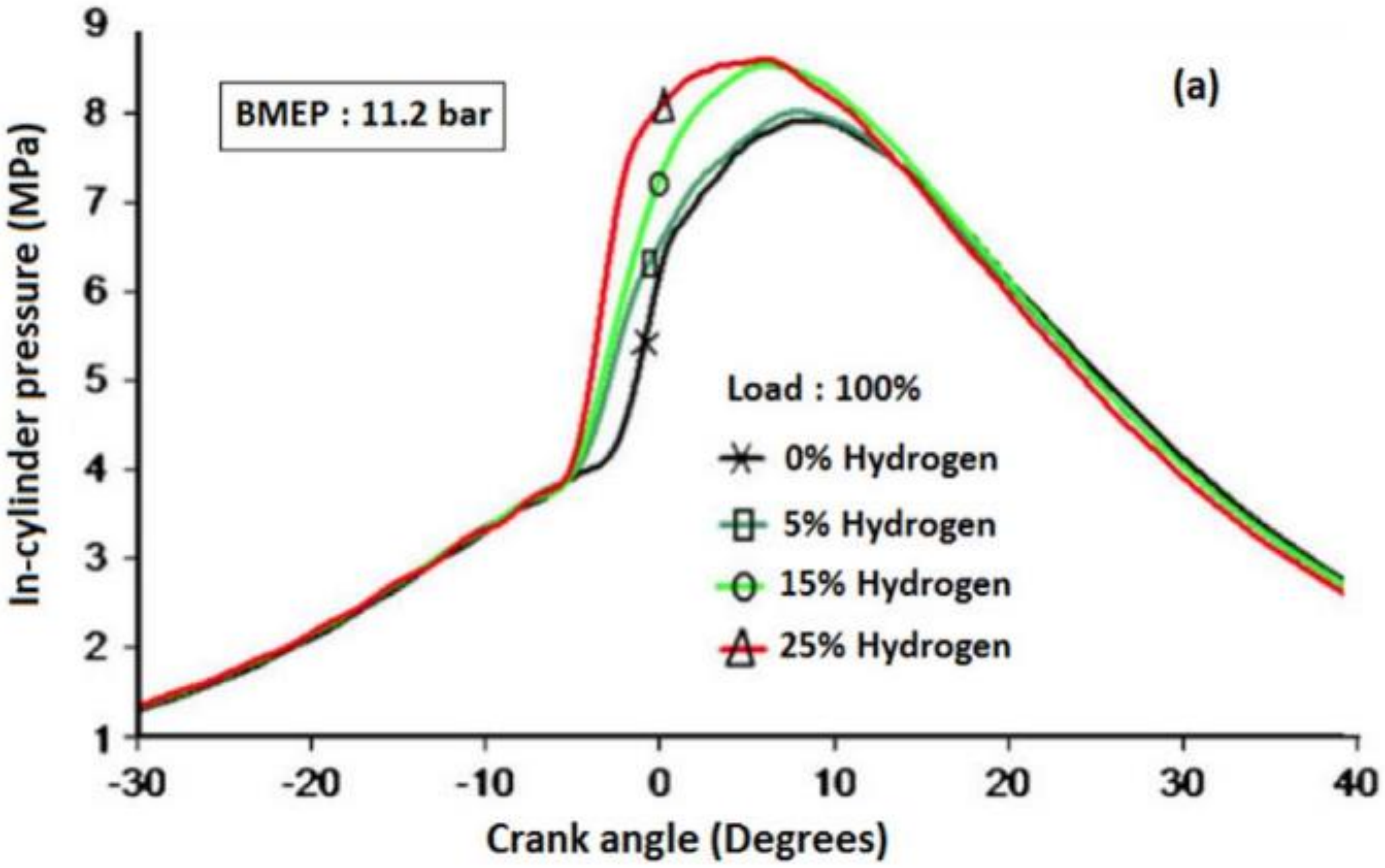


(a)
95
90
85
80
75
Volumetric efficiency (%)
0
2
4
6
8
10
12
14
16
18
Hydrogen energy share (%)
100% load (BMEP: 5.3 bar)
75% load (BMEP: 3.99 bar)
(b)
64.0
63.0
62.0
61.0
60.0
59.0
58.0
57.0
56.0
55.0
Volumetric efficiency (%)
0
5
10
15
20
25
30
35
40
Brake power (kW)
0 % Hydrogen
5 % Hydrogen
10 % Hydrogen
15 % Hydrogen
20 % Hydrogen

HİDROJEN

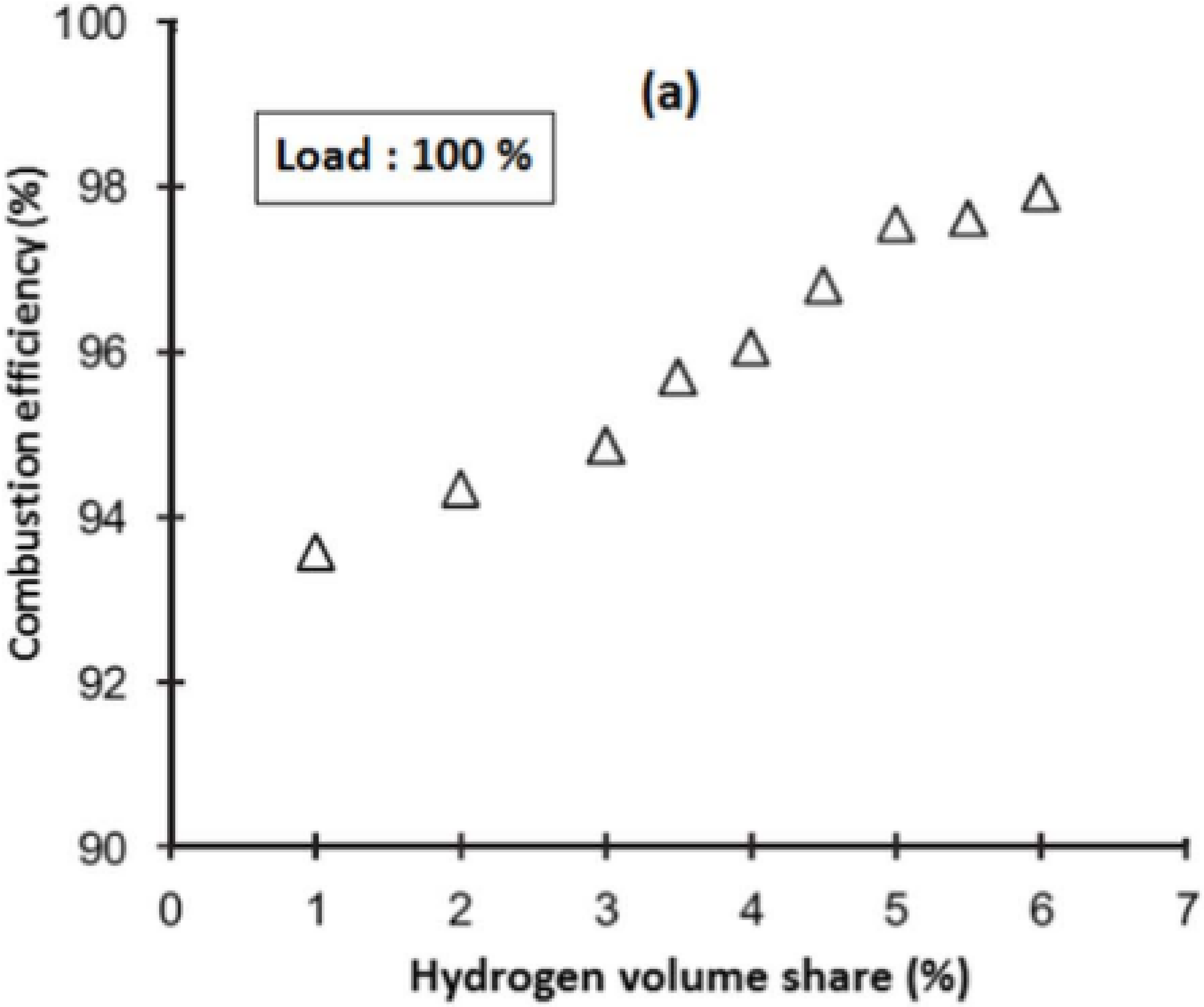

(a)
Exhaust gas temperature (deg.C)
500
450
400
350
300
250
0
2
4
6
8
10
12
14
16
18
Hydrogen energy share (%)
100% load (BMEP: 5.3 bar)
75% load (BMEP: 3.99 bar)
(b)
Exhaust gas temperature (deg.C)
600
500
400
0
10
20
Hydrogen energy share (%)
100% load (BMEP : 5.8 bar)
82% load (BMEP : 4.7 bar)

HİDROJEN

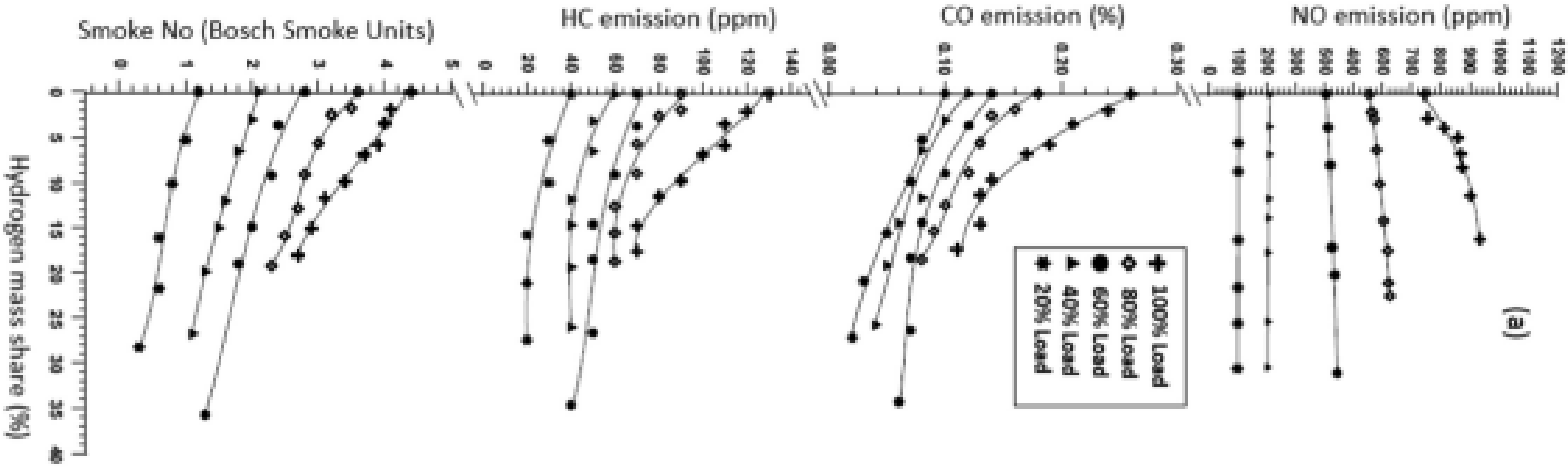


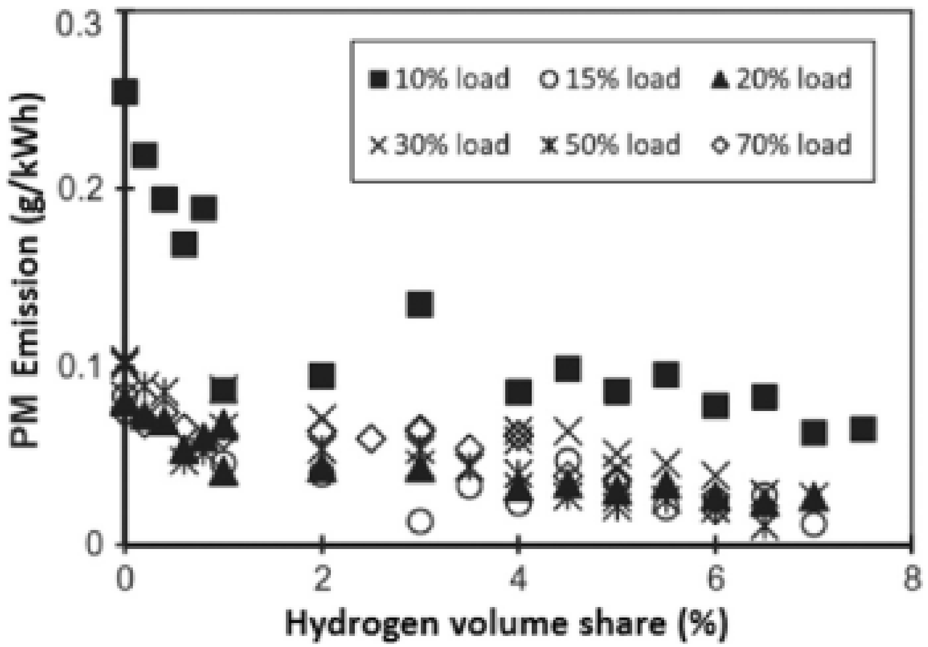
BMEP : 11.2 bar
(a)
In-cylinder pressure (MPa)
9
8
7
6
5
4
3
2
1
Load : 100%
0% Hydrogen
5% Hydrogen
15% Hydrogen
25% Hydrogen
-30
-20
-10
0
10
20
30
40
Crank angle (Degrees)

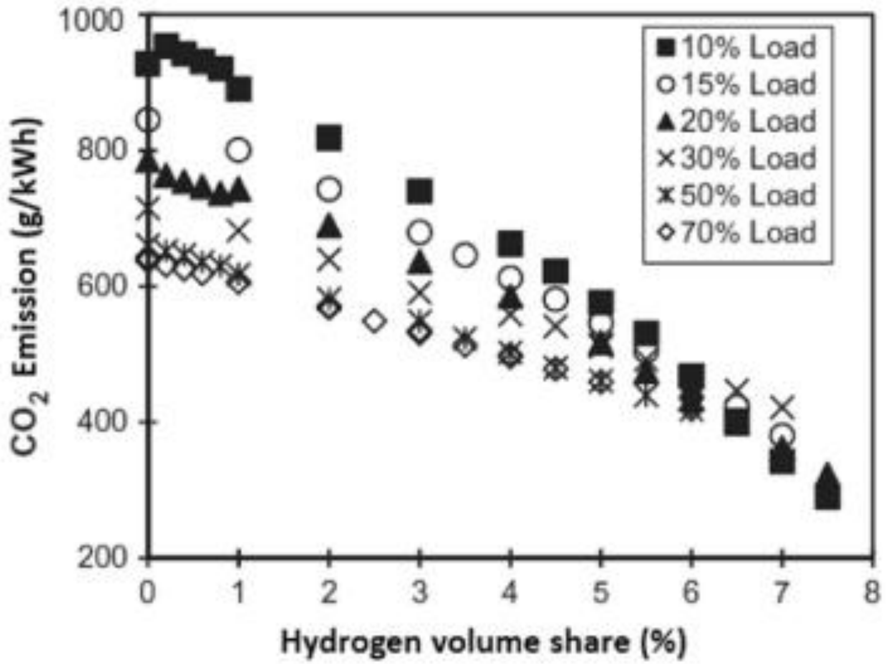
HİDROJEN



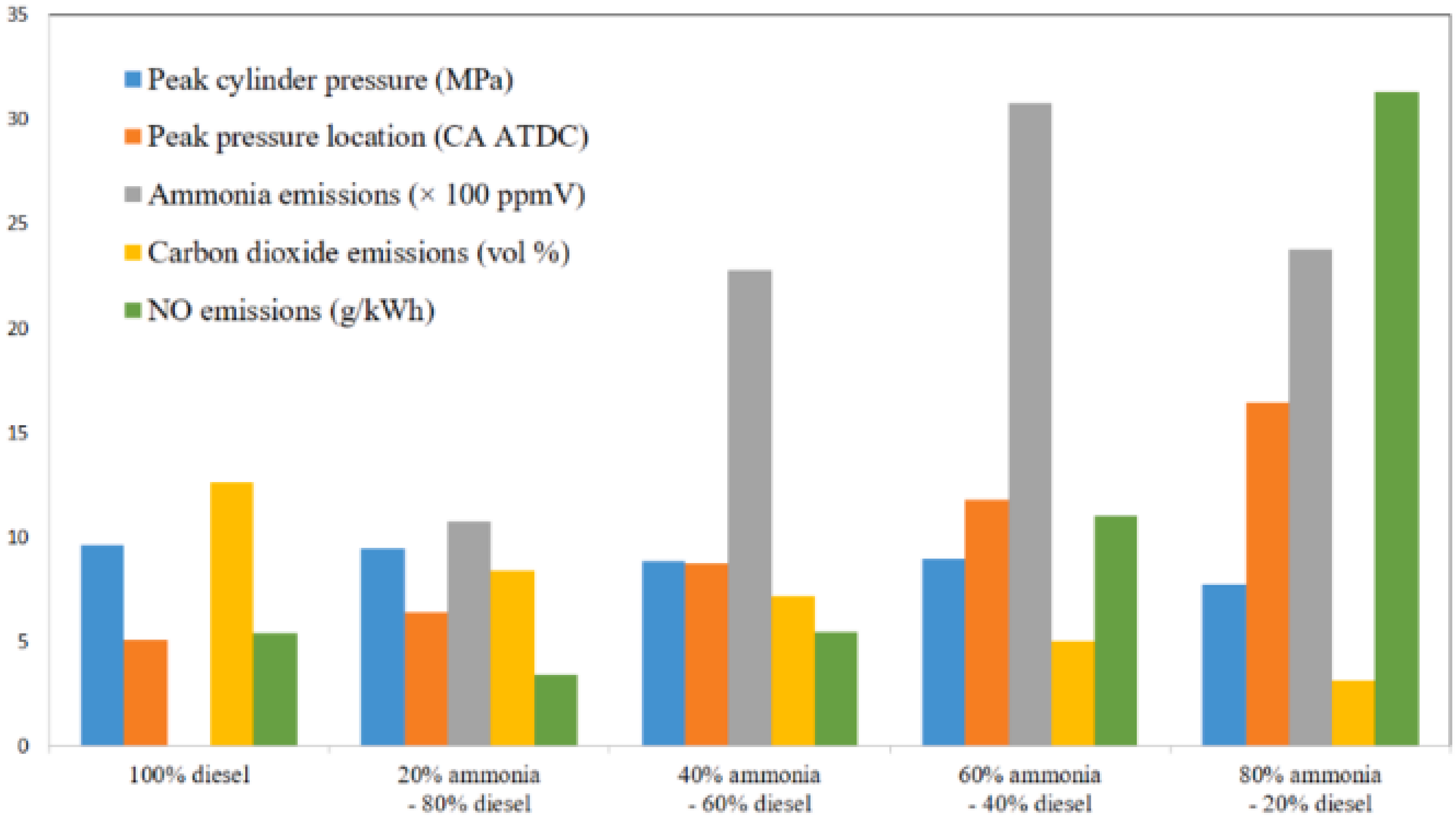
(a)
Load : 100 %
Combustion efficiency (%)
100
98
96
94
92
90
0
1
2
3
4
5
6
7
Hydrogen volume share (%)


Smoke No (Bosch Smoke Units)
HC emission (ppm)
CO emission (%)
NO emission (ppm)
Hydrogen mass share (%)
20% Load
40% Load
60% Load
80% Load
100% Load
(a)


10% load
15% load
20% load
30% load
50% load
70% load
PM Emission (g/kWh)
Hydrogen volume share (%)

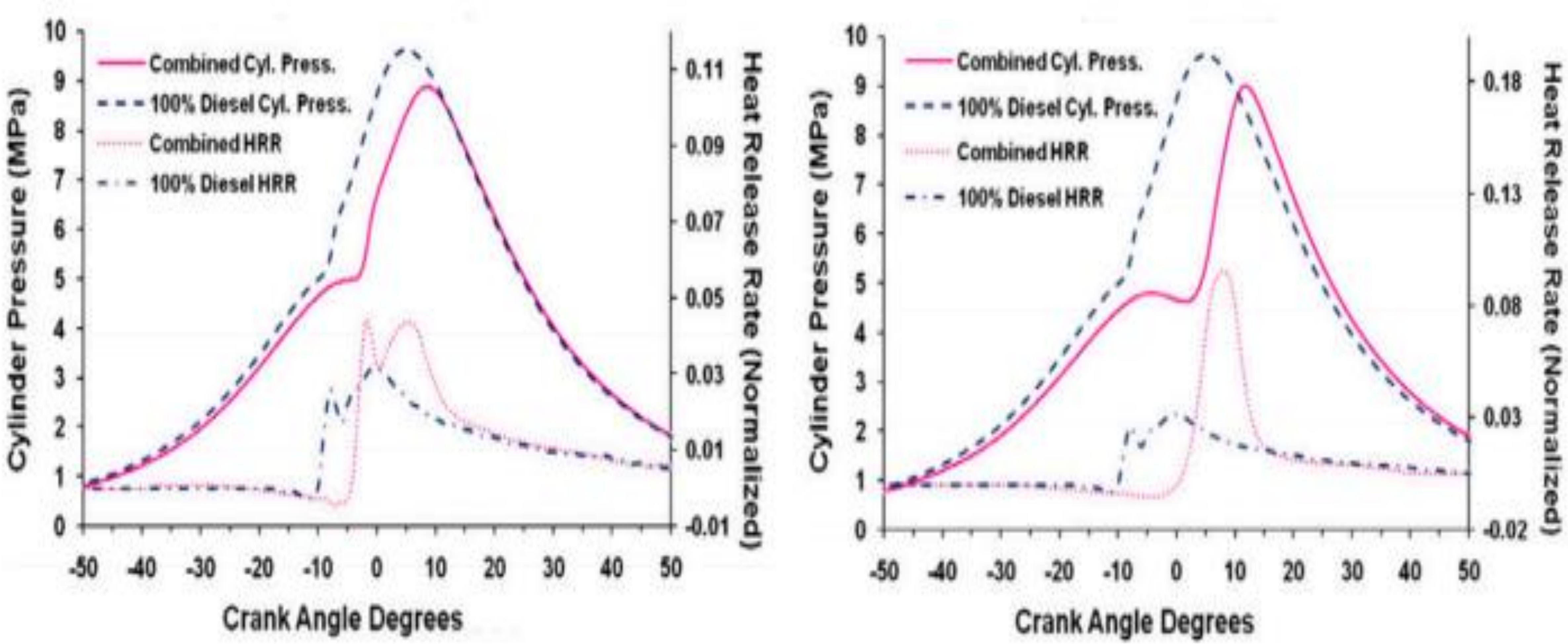

10% Load
15% Load
20% Load
30% Load
50% Load
70% Load
CO2 Emission (g/kWh)
Hydrogen volume share (%)

AMONYAK



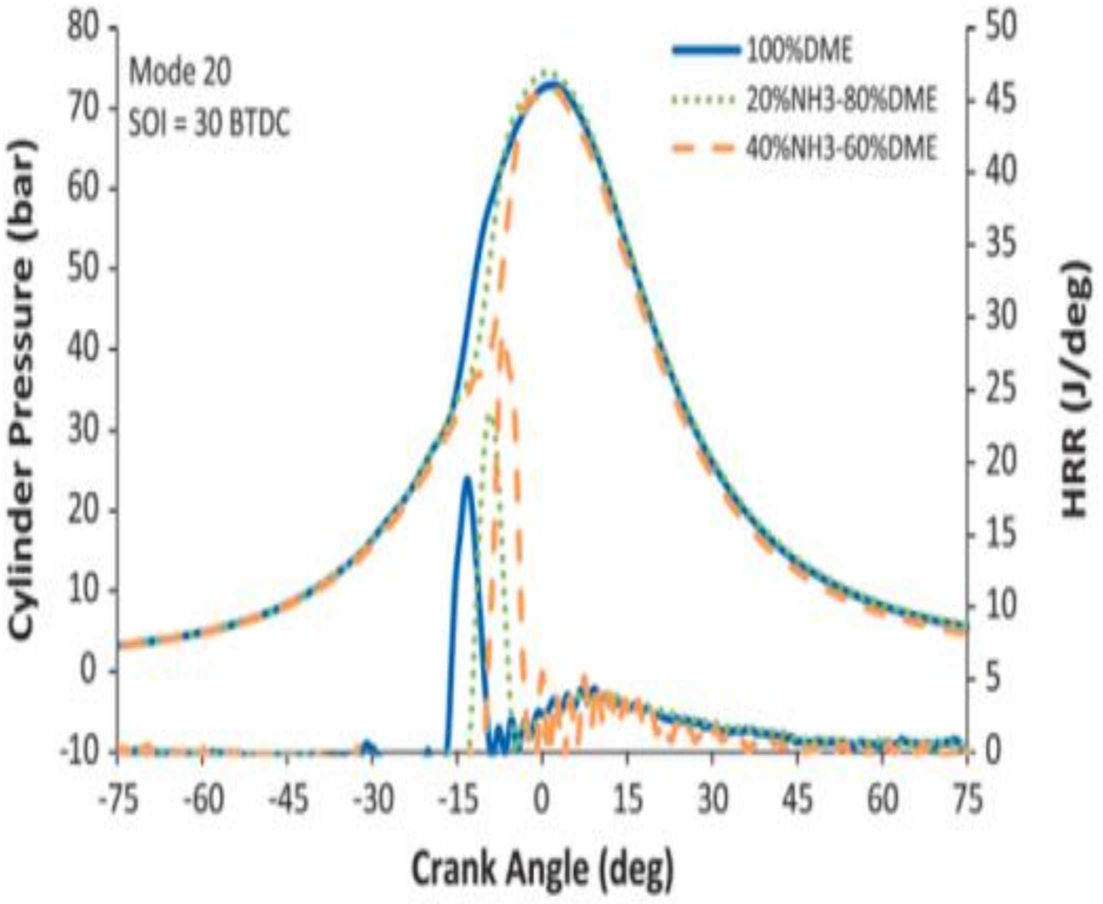
35
30
25
20
15
10
5
0
Peak cylinder pressure (MPa)
Peak pressure location (CA ATDC)
Ammonia emissions (× 100 ppmV)
Carbon dioxide emissions (vol %)
NO emissions (g/kWh)
100% diesel
20% ammonia - 80% diesel
40% ammonia - 60% diesel
60% ammonia - 40% diesel
80% ammonia - 20% diesel

AMONYAK

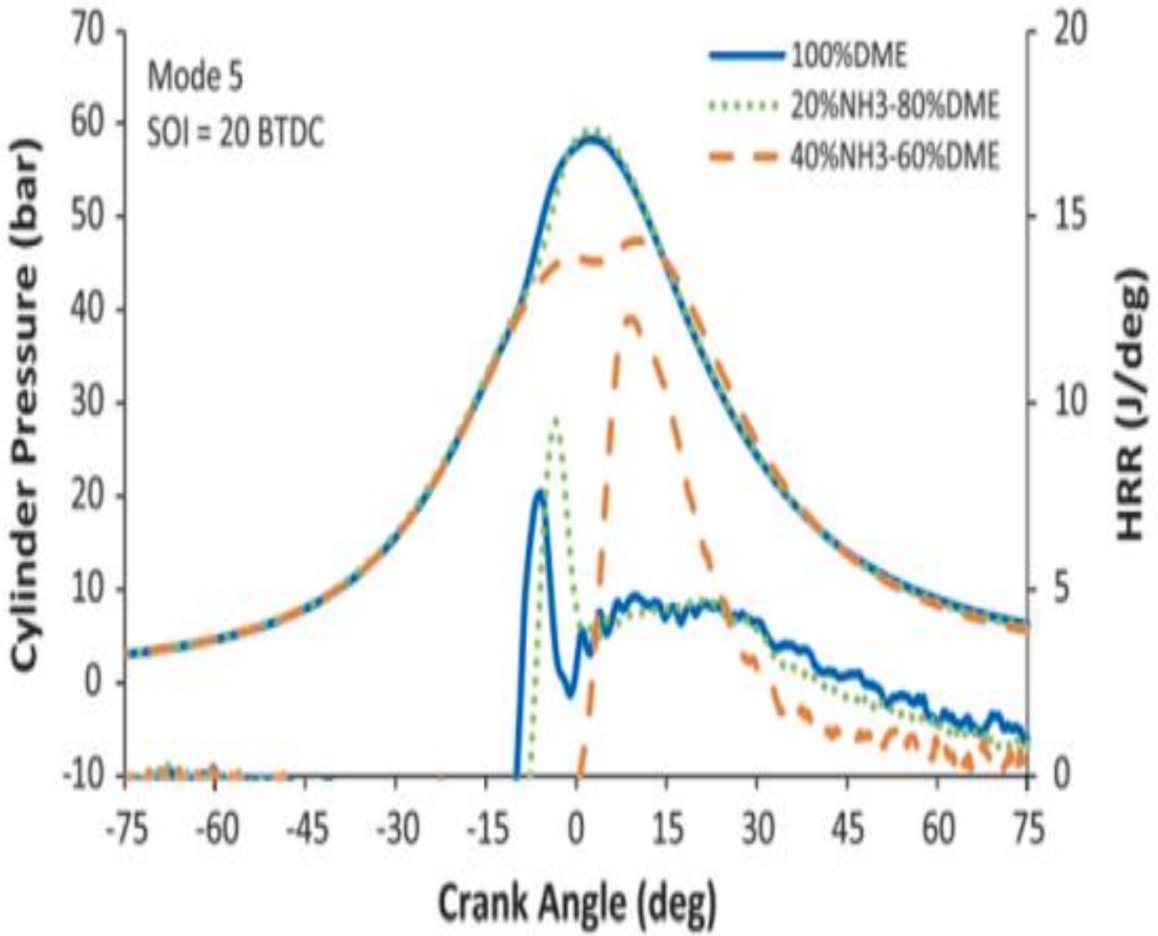


(a) 60% diesel + 40% ammonia and (b) 40% diesel + 60% ammonia

AMONYAK

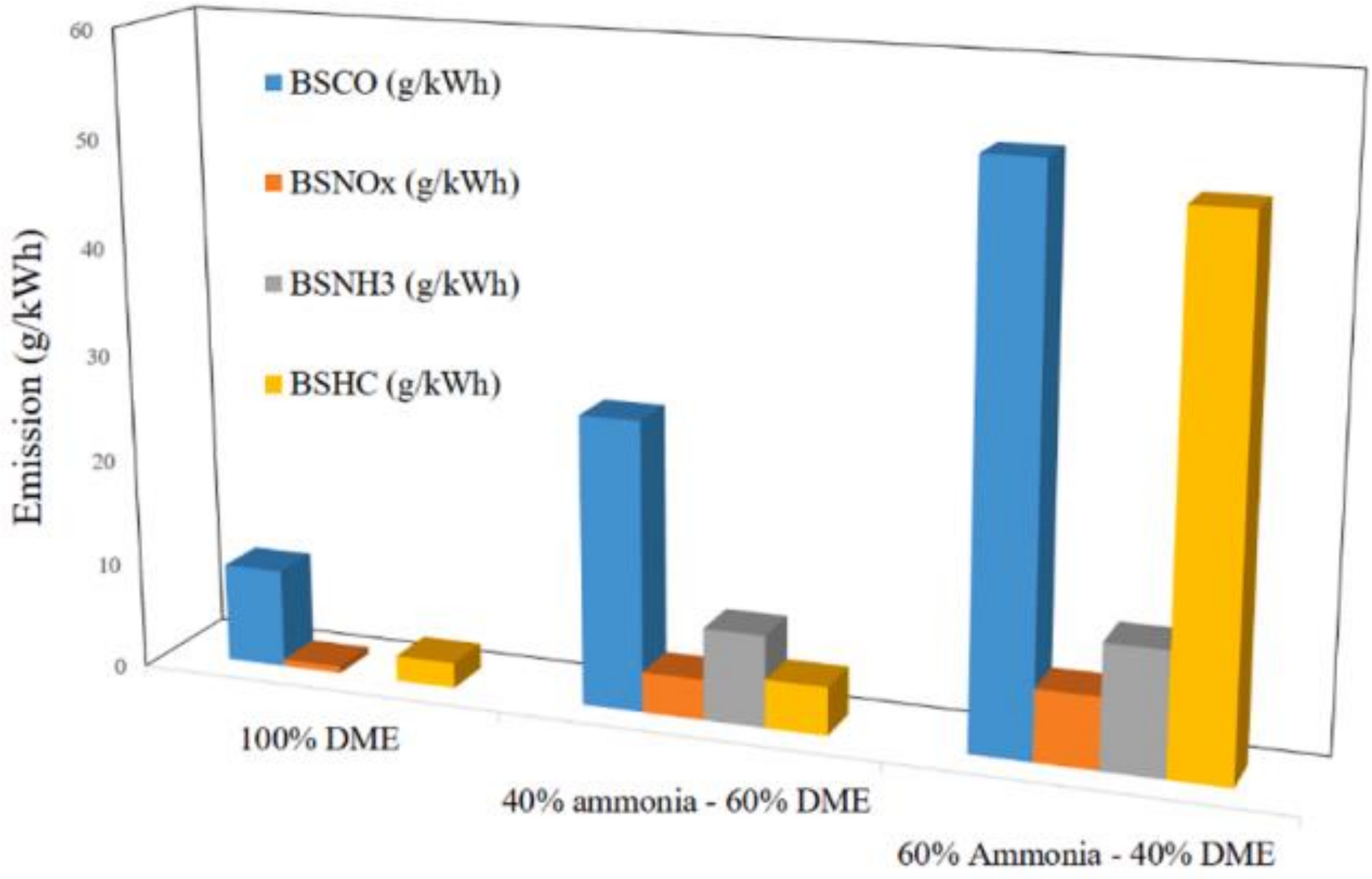


Mode 20
SOI = 30 BTDC
100%DME
20%NH3-80%DME
40%NH3-60%DME
Cylinder Pressure (bar)
HRR (J/deg)
Crank Angle (deg)



Mode 5
SOI = 20 BTDC
100%DME
20%NH3-80%DME
40%NH3-60%DME
Cylinder Pressure (bar)
HRR (J/deg)
Crank Angle (deg)

AMONYAK



Emission (g/kWh)
60
50
40
30
20
10
0
BSCO (g/kWh)
BSNOx (g/kWh)
BSNH3 (g/kWh)
BSHC (g/kWh)
100% DME
40% ammonia - 60% DME
60% Ammonia - 40% DME

AMONYAK

Journal of the Energy Institute 114 (2024) 101641

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Investigation on the combustion of ammonia using direct high/medium-pressure-Otto injection approach in a diesel two-stroke marine slow speed engine

Antony John Nyongesa [a,b], Jeong Kuk Kim [c], Won-Ju Lee [d,e,*]

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[b] *Large Engines Competence Center, Graz, 8010, Austria*
[c] *Division of Marine Engineering, Korea Maritime and Ocean University, Busan, 49112, South Korea*
[d] *Interdisciplinary Major of Maritime AI Convergence, Korea Maritime and Ocean University, Busan, 49112, South Korea*
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A R T I C L E I N F O

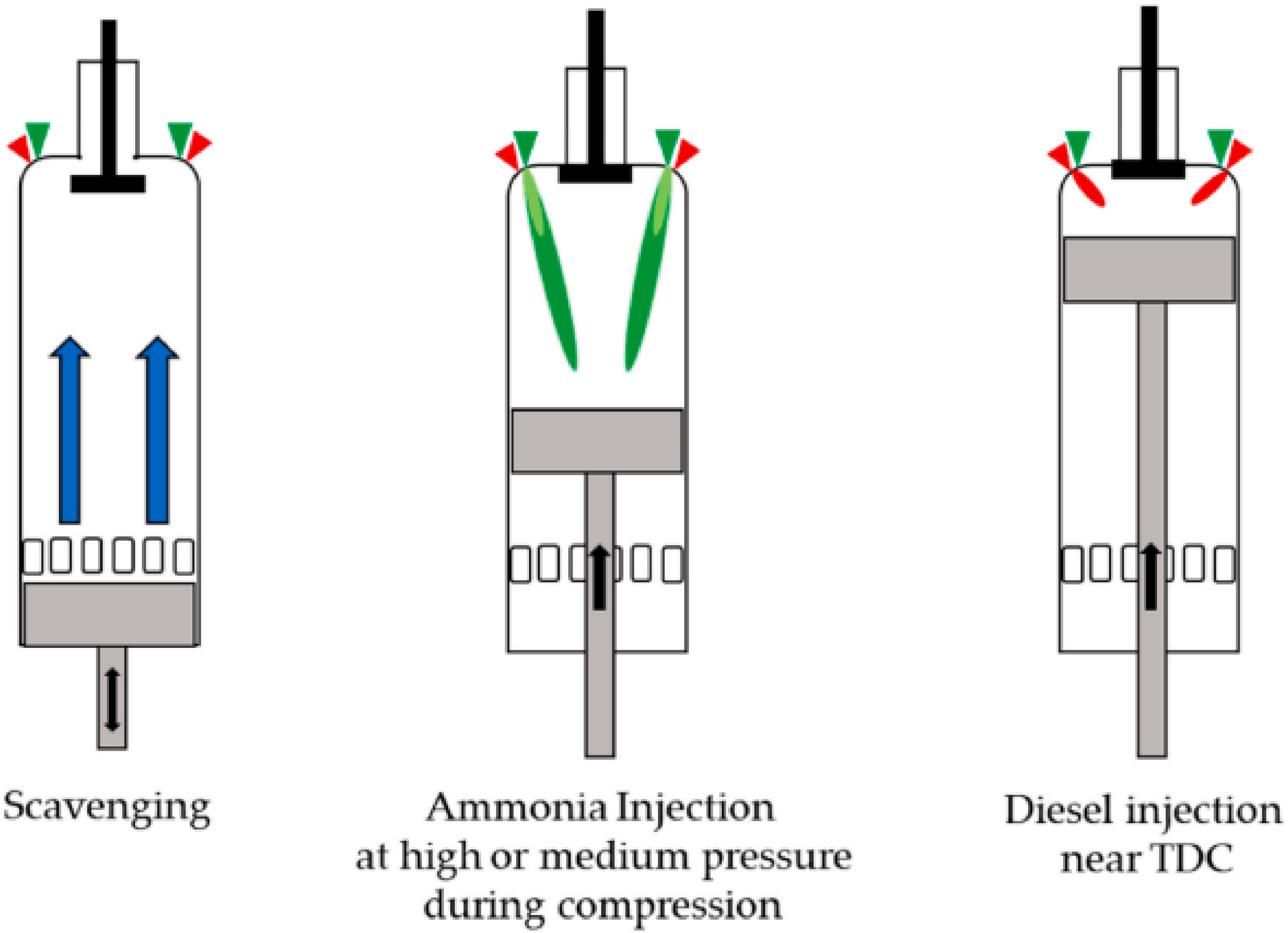
Handling Editor: Dr. Paul Williams

Keywords:
Ammonia
Dual-fuel
Injection strategy
Emissions
Two-stroke engine

A B S T R A C T

The urgent need to reduce exhaust gas emissions has led to increased research activities on the potential of using ammonia as fuel in marine engines. Various researchers have already investigated the combustion of ammonia specifically in two-stroke, slow-speed marine engines, and obtained promising results. In the available literature, both high-pressure direct injection-Diesel (HPDF) and low-pressure direct injection dual fuel - Otto (LPDF) two-stroke engines have been well-researched. This study numerically investigates the potential of using a direct high/medium pressure (Otto) ammonia injection strategy on a marine two-stroke engine. A diesel-fueled engine was retrofitted with ammonia injectors on the cylinder head. The effects of ammonia injection direction, timing, and injection pressure on the combustion efficiency, engine performance, and exhaust gas emissions were

AMONYAK


Scavenging
Ammonia Injection
at high or medium pressure
during compression
Diesel injection
near TDC

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International Journal of Hydrogen Energy 64 (2024) 186–195

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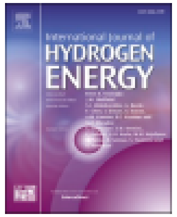


Check for updates

The effects of ammonia addition on the emission and performance characteristics of a diesel engine with variable compression ratio and injection timing

Fatih Okumuş [a], Berna Kanberoğlu [b,*], Güven Gonca [a], Görkem Kökkülünk [b], Zafer Aydın [c], Cenk Kaya [d]

[a] Yildiz Technical University, Naval Architecture and Marine Engineering Department, Istanbul, Turkey
[b] Yildiz Technical University, Marine Engineering Department, Istanbul, Turkey
[c] Piri Reis University, Marine Engineering Department, Istanbul, Turkey
[d] Istanbul Technical University, Marine Engineering Department, Istanbul, Turkey

A R T I C L E I N F O

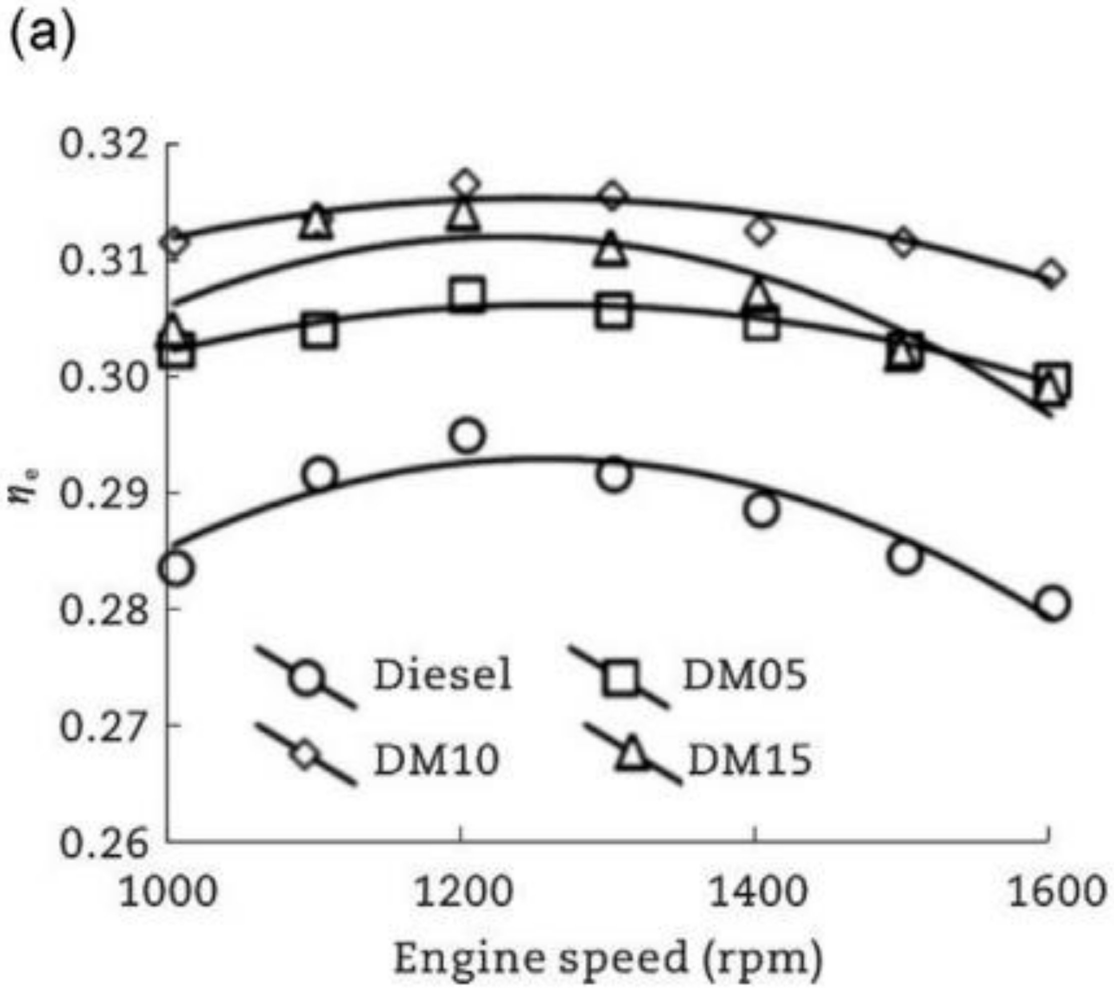
Handling editor: J. W. Sheffield

Keywords:
Ammonia
Injection timing
Compression ratio
Engine performance
Emissions

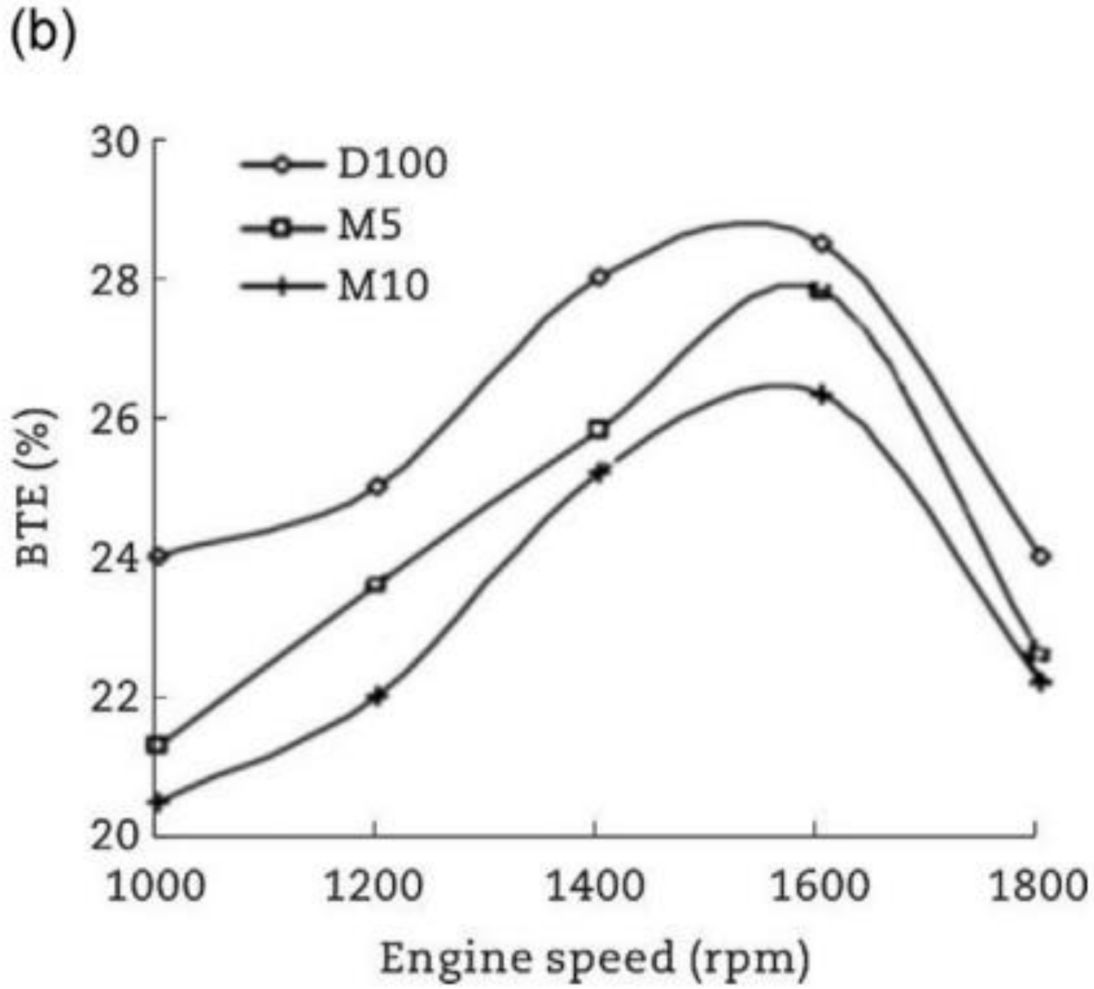
A B S T R A C T

Ammonia, future of the carbonless marine fuel, presents significant potential in achieving zero-emission targets within maritime transportation. In this context, this study explores the use of an ammonia/diesel fuel mixture in a diesel engine, employing both experimental and numerical methods. We focus on the impact of injection timing and compression ratio to optimize the engine while using ammonia/diesel mixture in terms of both engine performance and exhaust emissions. The results show a decrease in engine power with an increasing content of ammonia, reaching the lowest power of 4.53 kW at 60% ammonia content. On the other hand, the increase in compression ratio generally enhances engine power. Thermal efficiency shows an increase up to 40% ammonia content, followed by a decline. CO_2 emissions significantly reduce with an increase in ammonia content, reaching the lowest level, especially at 60% ammonia content. NO emissions rise with increasing ammonia content up to 40%. Furthermore, increasing the compression ratio reduces CO_2 emissions and contributes to an increase in NO_x emissions. These findings have assessed the potential usage of ammonia-diesel fuel mixture with regards to environmental impacts and energy efficiency in internal combustion engines.

METANOL

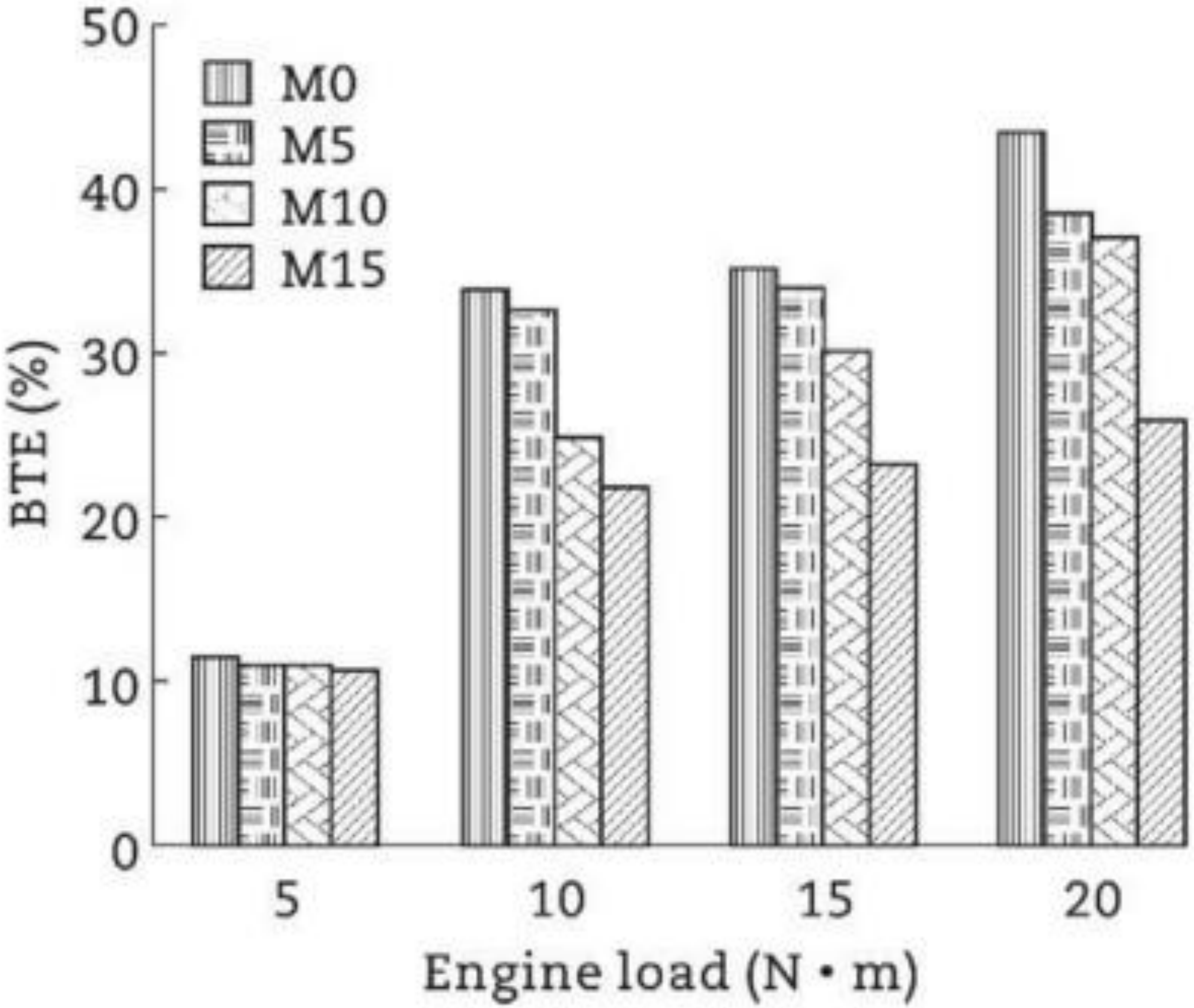


(a)
0.32
0.31
0.30
0.29
0.28
0.27
0.26
η_e
1000
1200
1400
1600
Engine speed (rpm)
Diesel
DM05
DM10
DM15

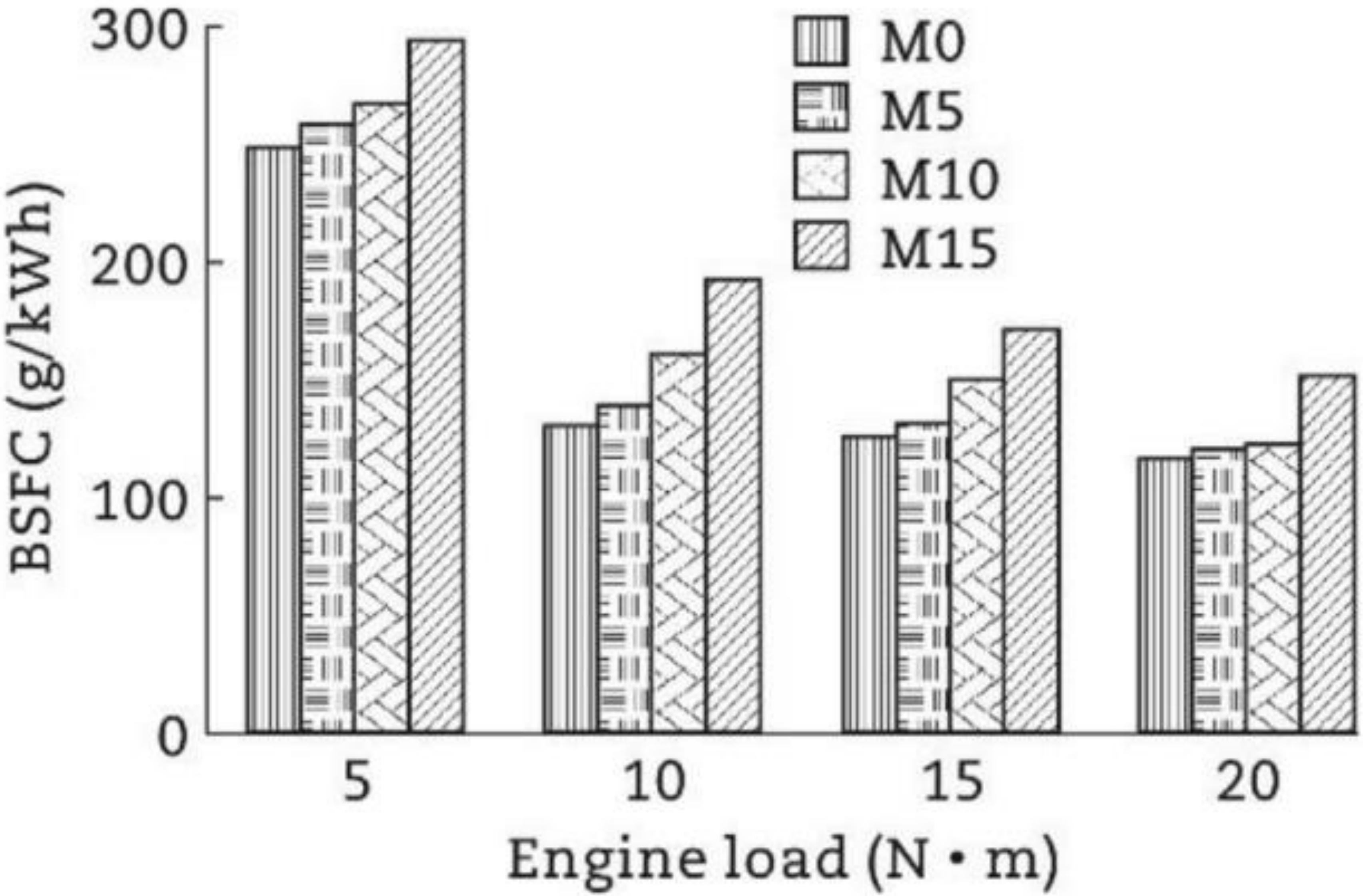


(b)
30
28
26
24
22
20
BTE (%)
D100
M5
M10
1000
1200
1400
1600
1800
Engine speed (rpm)

METANOL



METANOL



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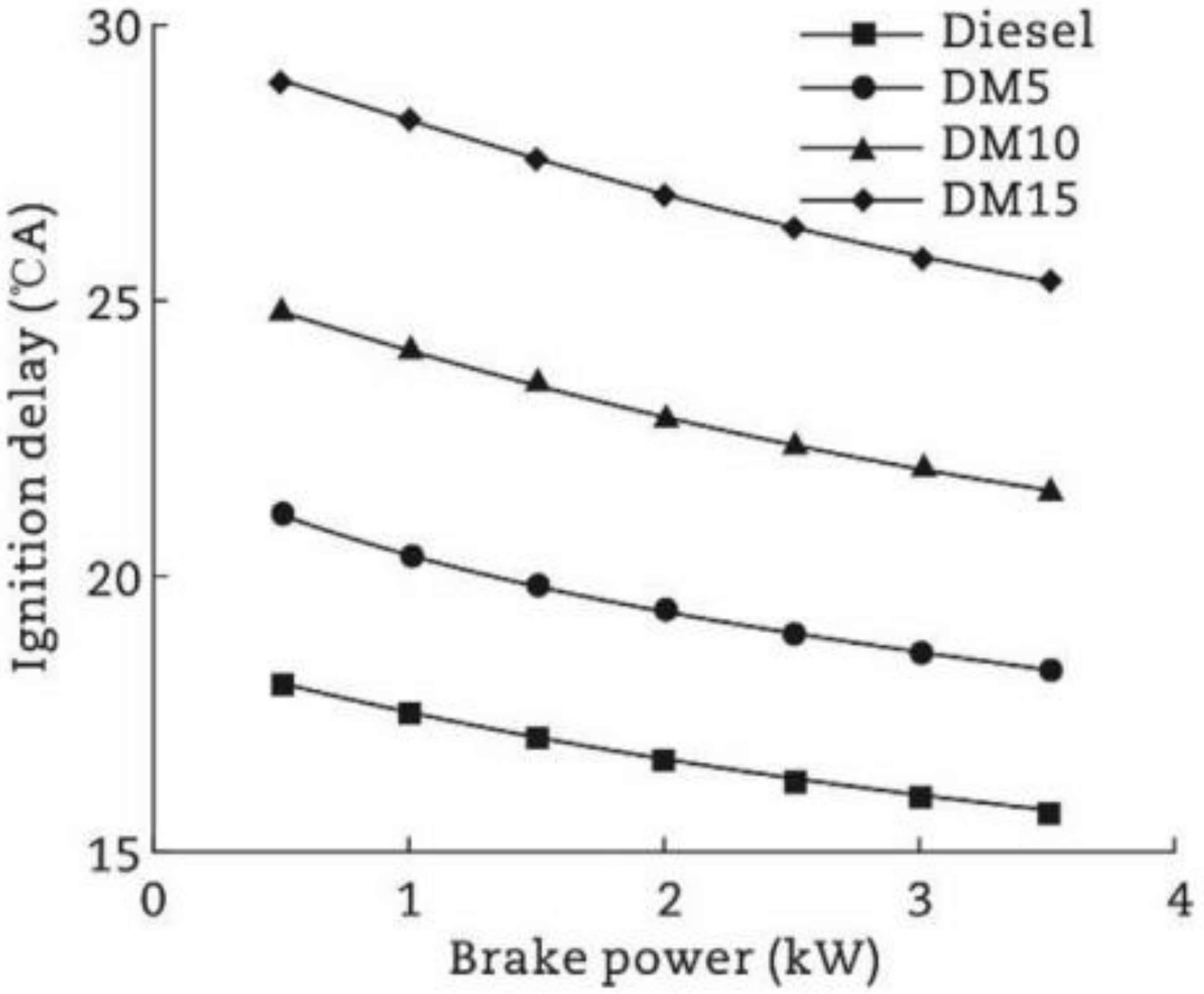
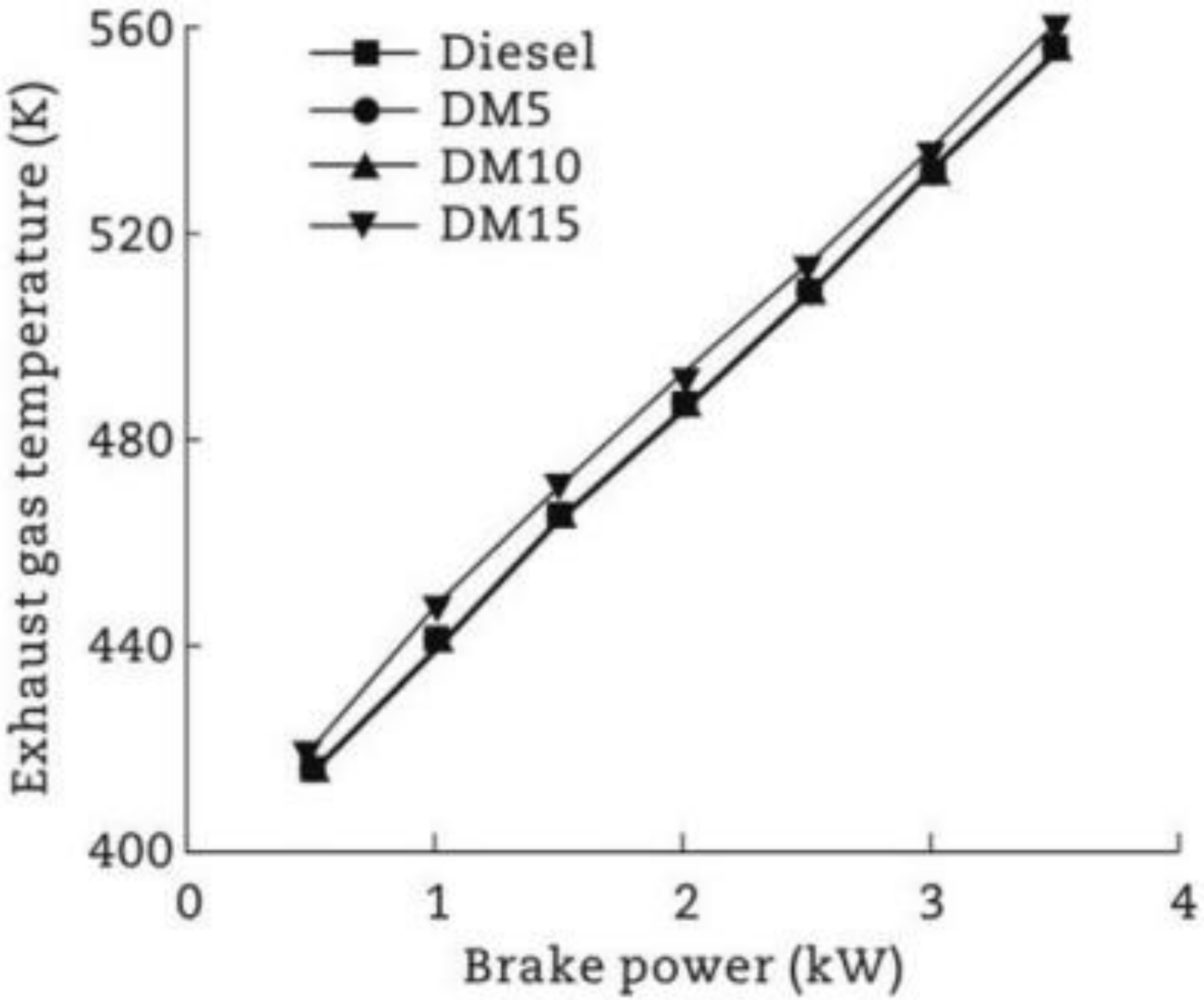


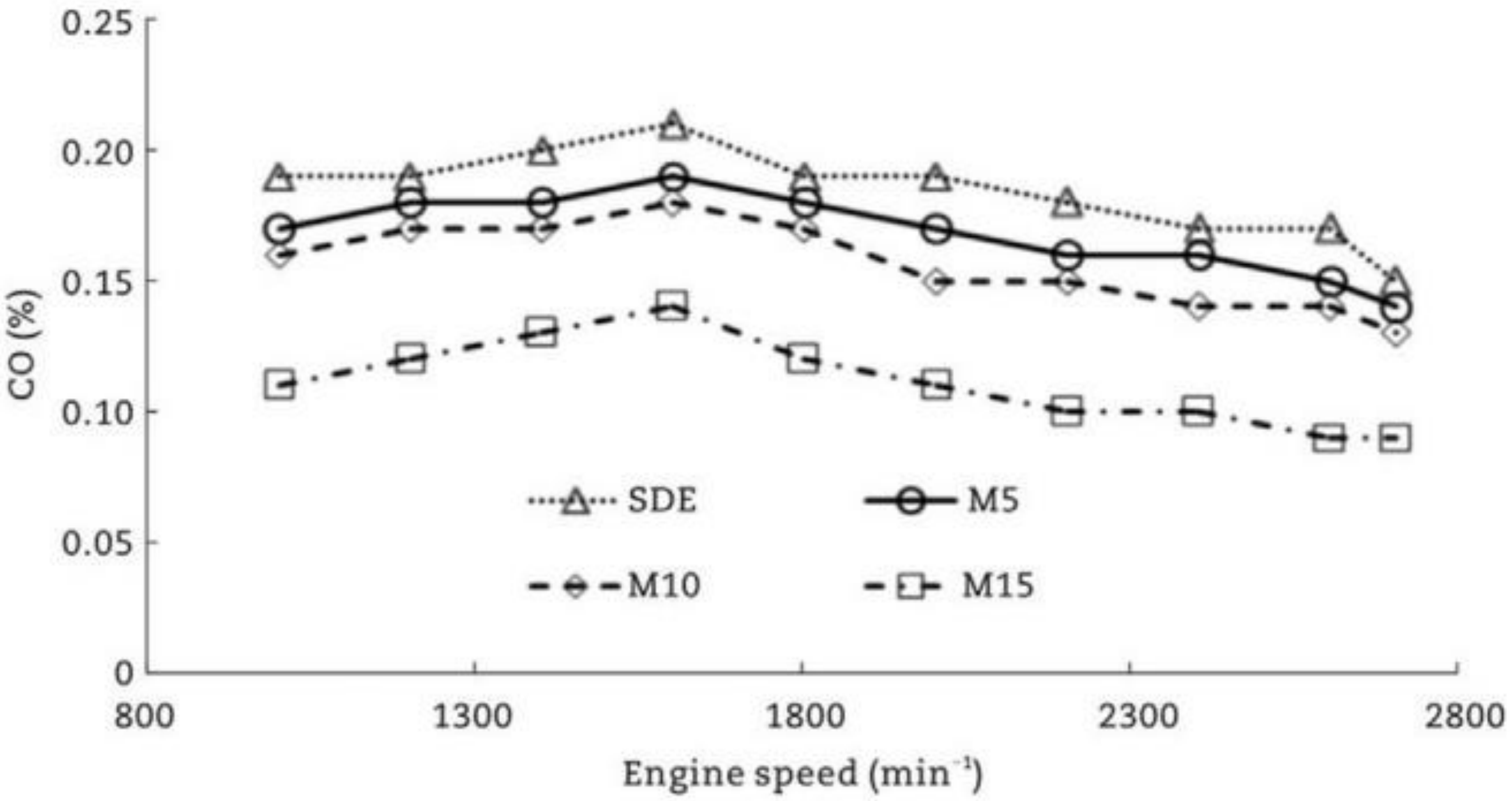
Ignition delay (℃A)
30
25
20
15
0
1
2
3
4
Brake power (kW)
Diesel
DM5
DM10
DM15

METANOL



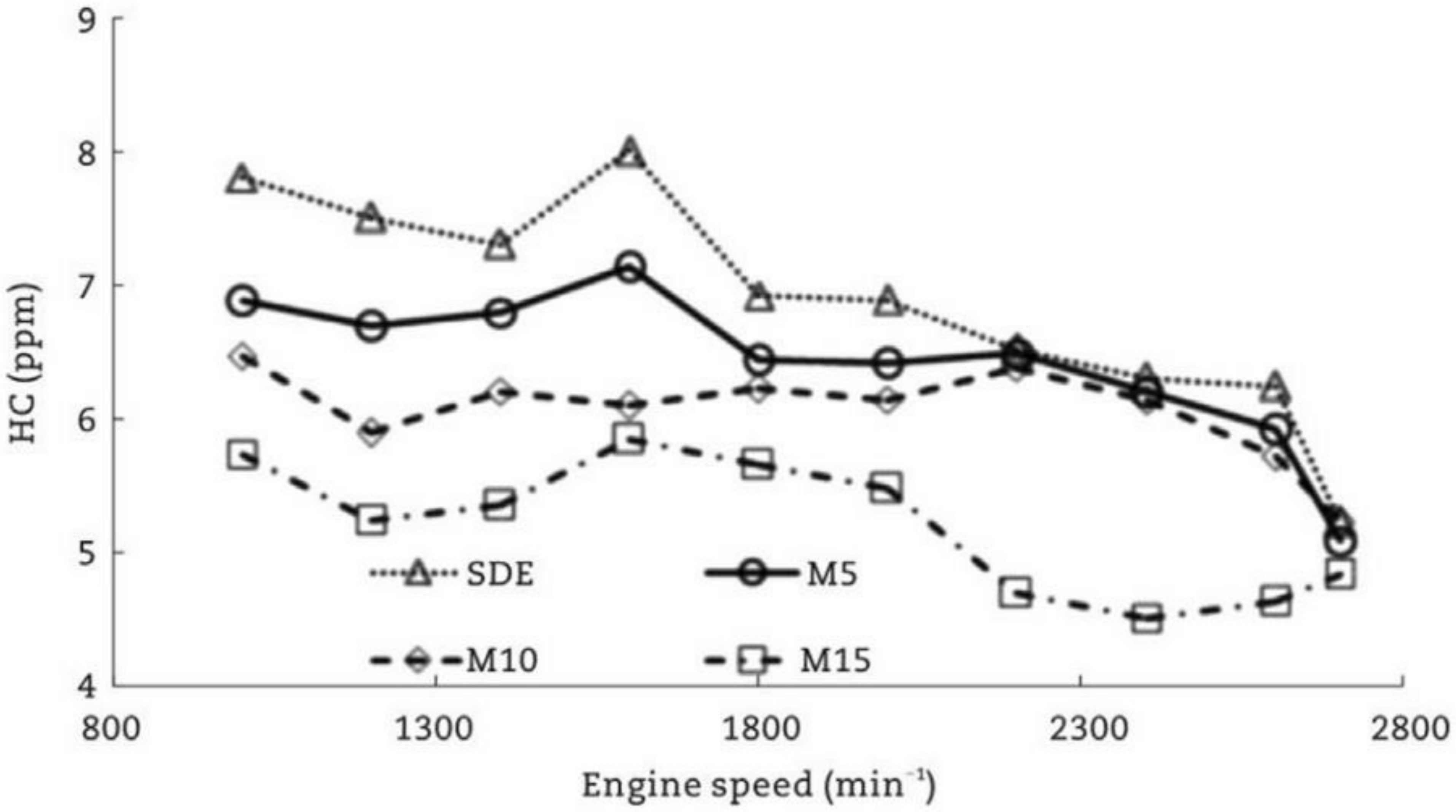
Diesel
DM5
DM10
DM15
Exhaust gas temperature (K)
Brake power (kW)
560
520
480
440
400
0
1
2
3
4

METANOL



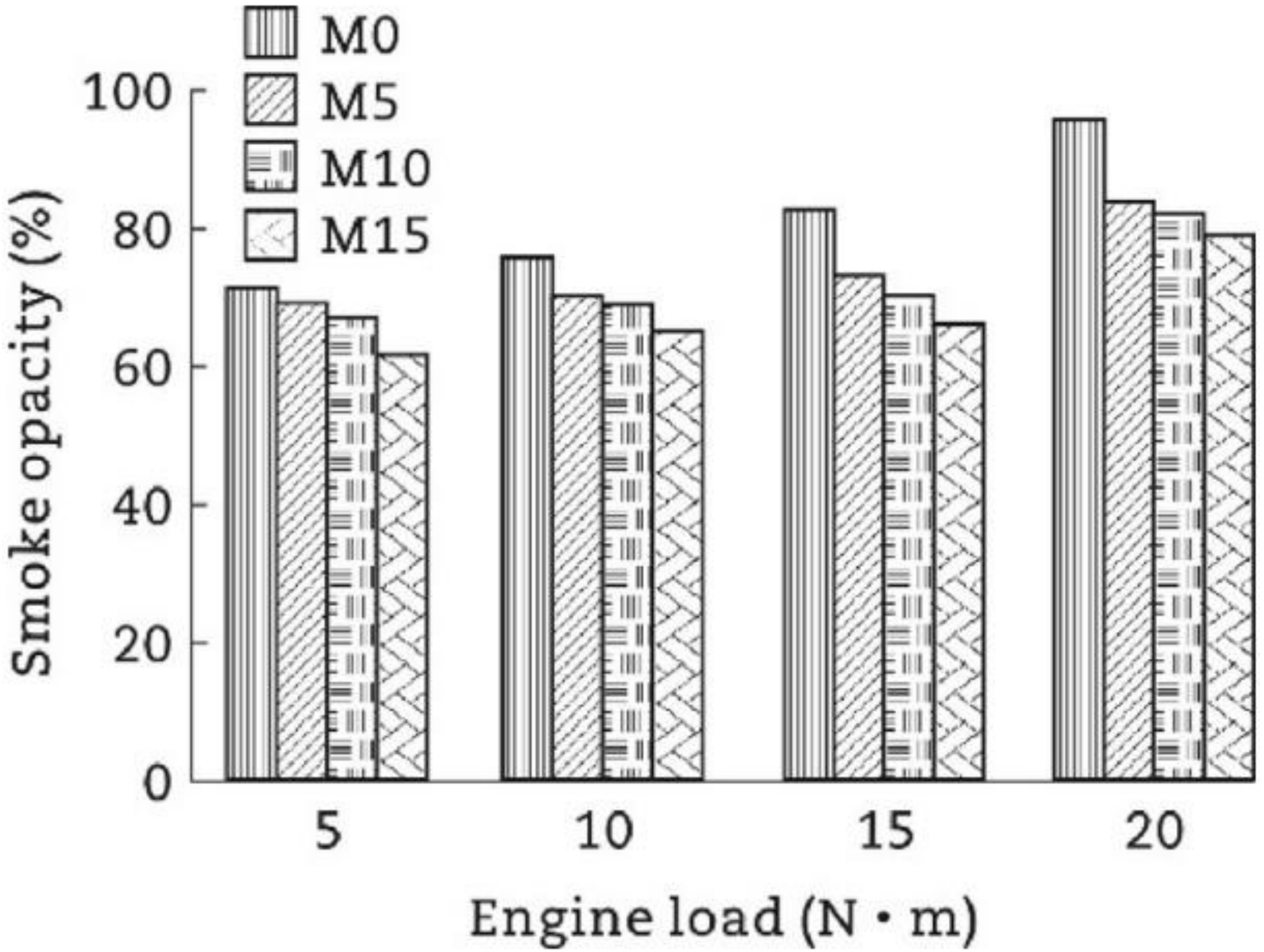
0.25
0.20
0.15
0.10
0.05
0
CO (%)
SDE
M5
M10
M15
800
1300
1800
2300
2800
Engine speed (min⁻¹)

METANOL

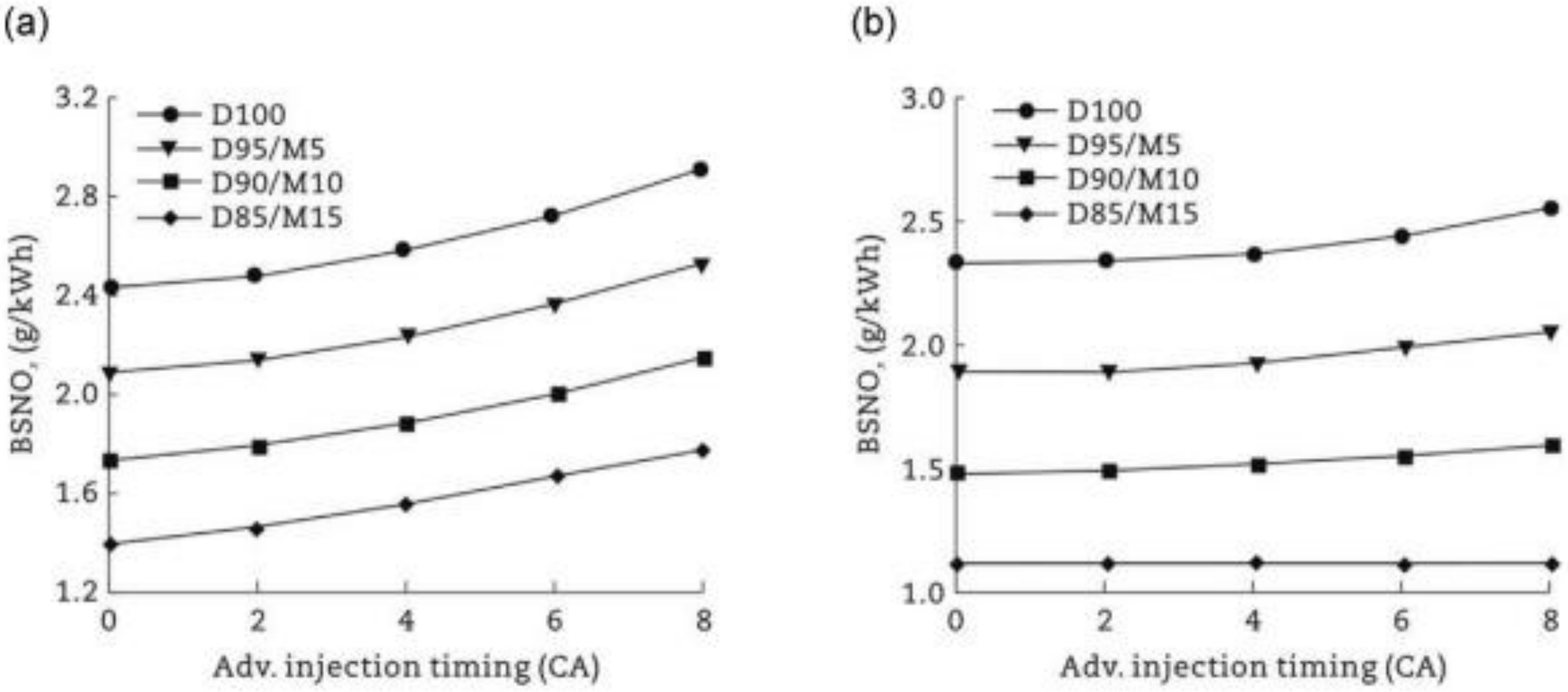


9
8
7
6
5
4
HC (ppm)
SDE
M5
M10
M15
800
1300
1800
2300
2800
Engine speed (min⁻¹)

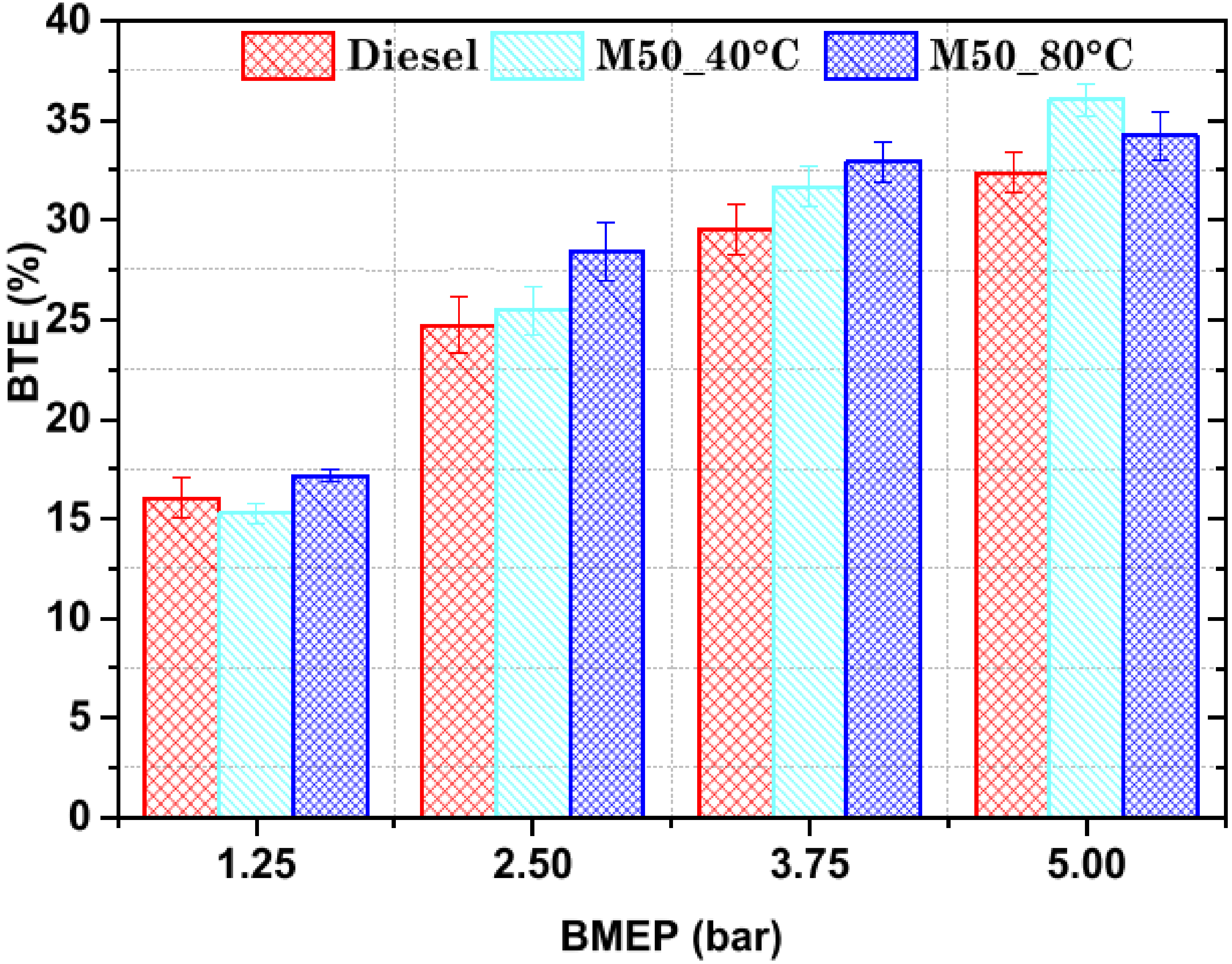
METANOL


M0
M5
M10
M15
Smoke opacity (%)
100
80
60
40
20
0
5
10
15
20
Engine load (N • m)

METANOL


(a)
3.2
2.8
2.4
2.0
1.6
1.2
0
2
4
6
8
D100
D95/M5
D90/M10
D85/M15
BSNO, (g/kWh)
Adv. injection timing (CA)
(b)
3.0
2.5
2.0
1.5
1.0
0
2
4
6
8
D100
D95/M5
D90/M10
D85/M15
BSNO, (g/kWh)
Adv. injection timing (CA)

METANOL



Diesel
M50_40°C
M50_80°C
BTE (%)
0
5
10
15
20
25
30
35
40
1.25
2.50
3.75
5.00
BMEP (bar)

METANOL

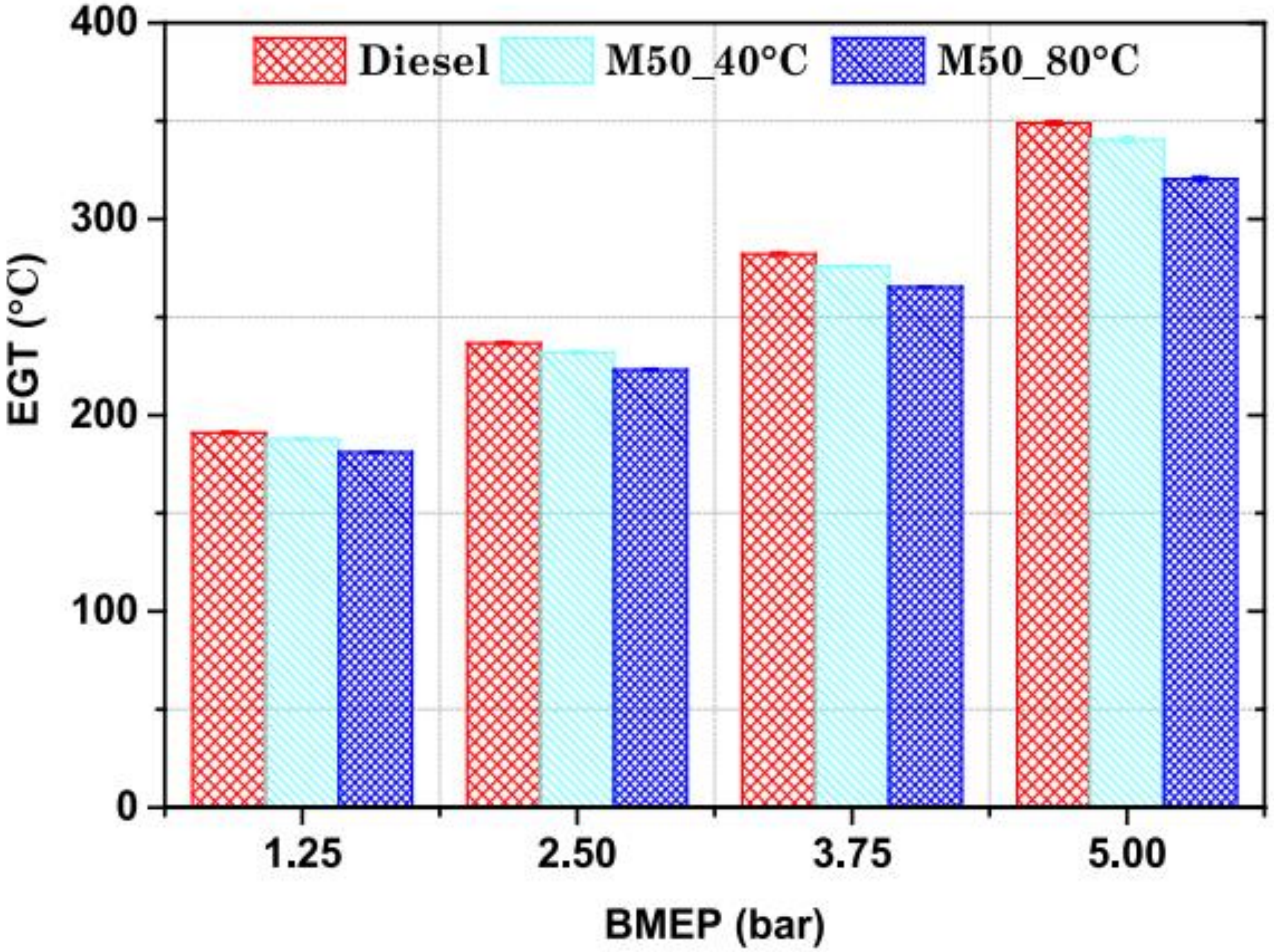
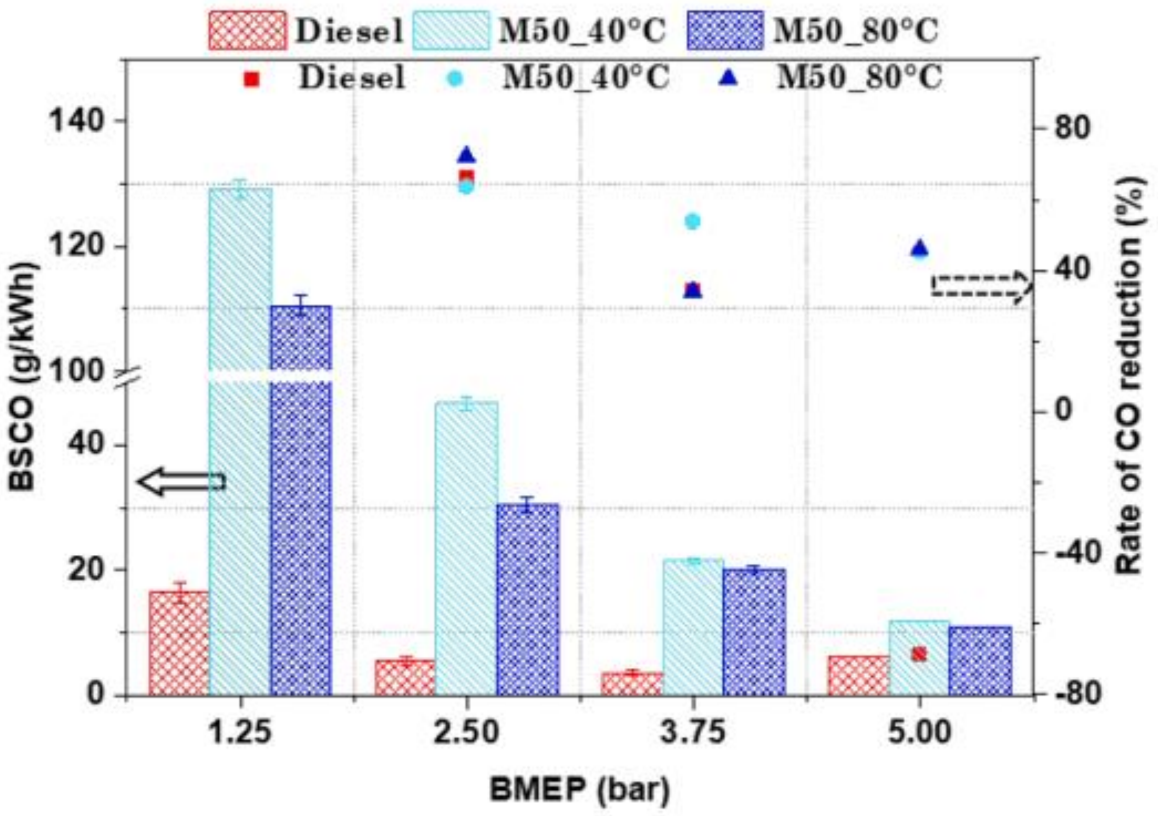
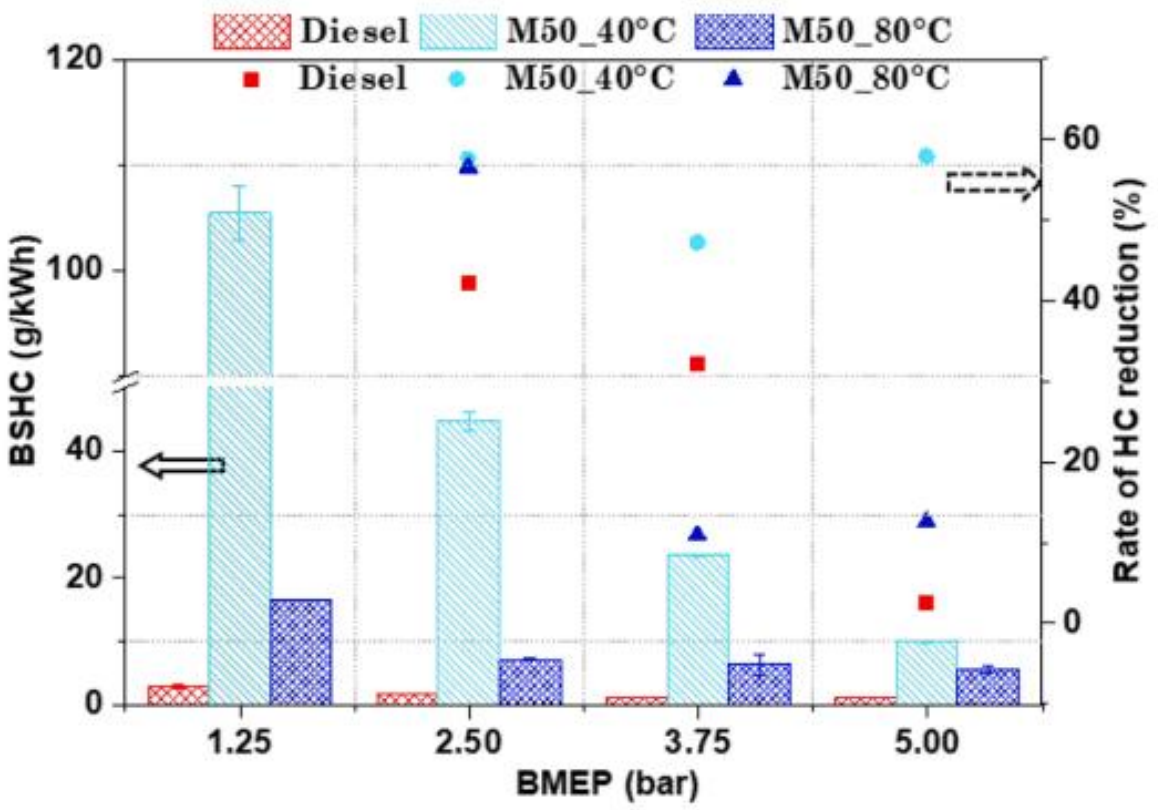


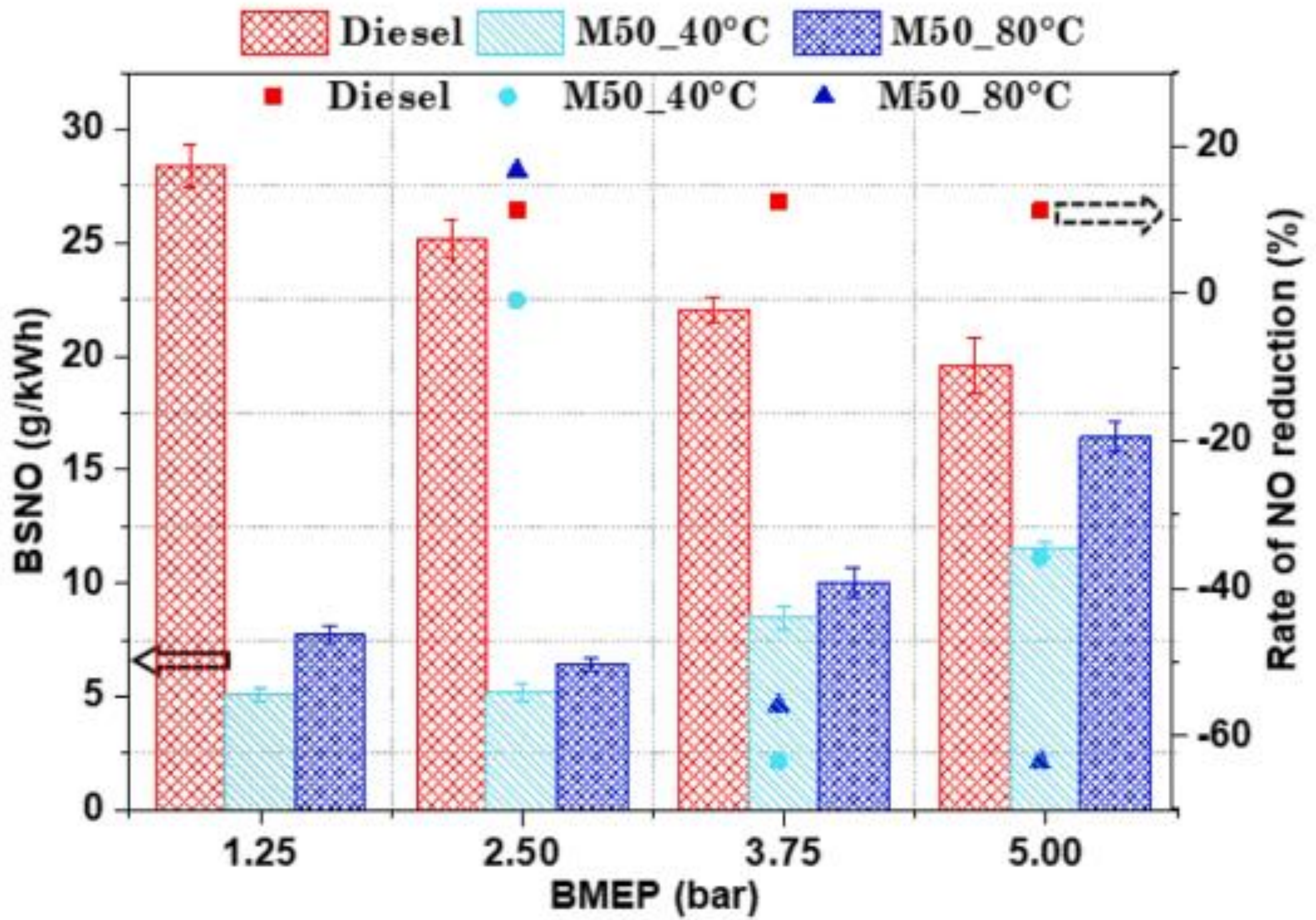
Fig. 8. Exhaust gas temperature (EGT) variations for varying engine loads.

METANOL


Diesel
M50_40°C
M50_80°C
Diesel
M50_40°C
M50_80°C
140
120
100
40
20
0
80
40
0
-40
-80
BSCO (g/kWh)
Rate of CO reduction (%)
1.25
2.50
3.75
5.00
BMEP (bar)

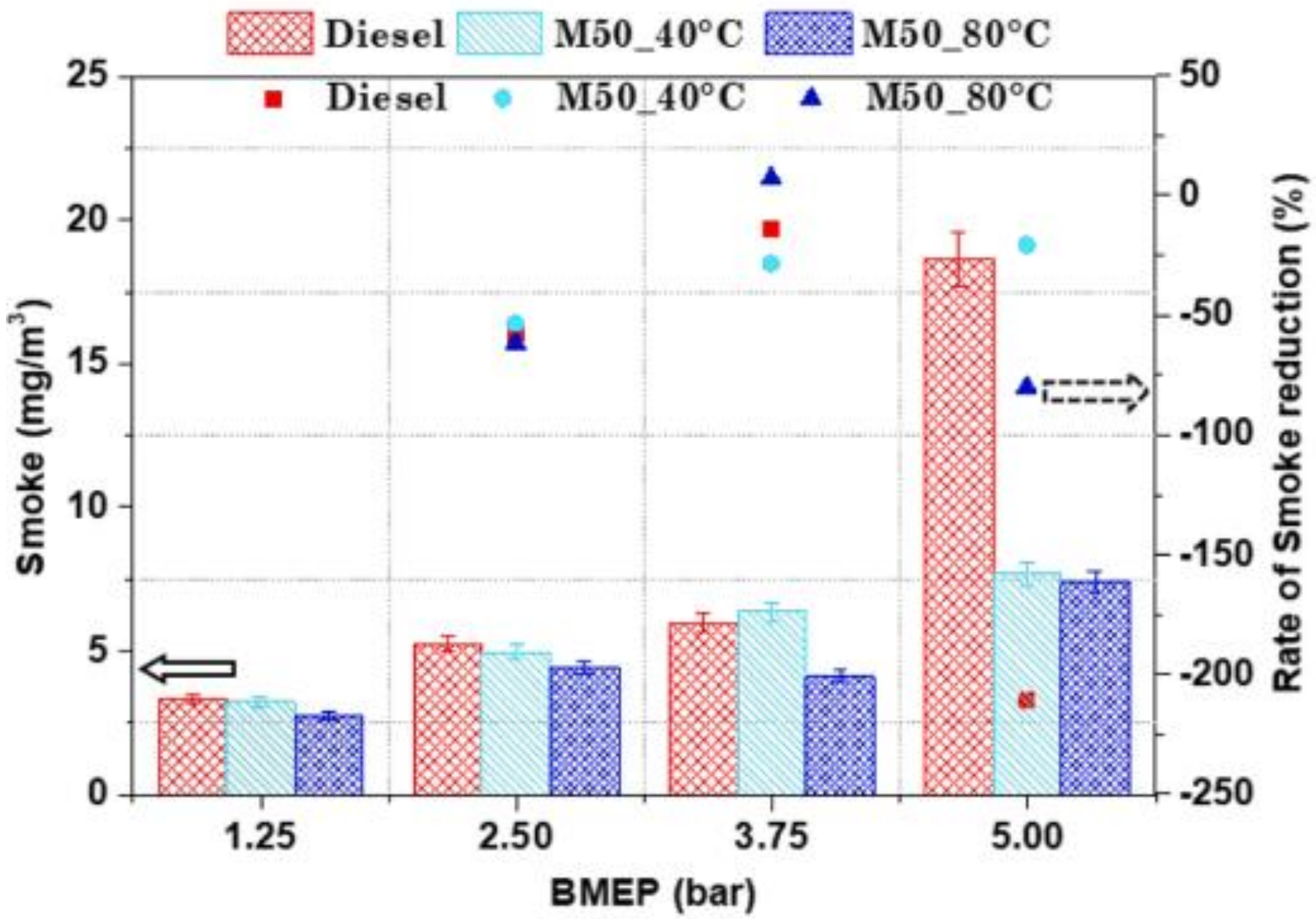

Diesel
M50_40°C
M50_80°C
Diesel
M50_40°C
M50_80°C
120
100
40
20
0
60
40
20
0
BSHC (g/kWh)
Rate of HC reduction (%)
1.25
2.50
3.75
5.00
BMEP (bar)

METANOL



Diesel
M50_40°C
M50_80°C
Diesel
M50_40°C
M50_80°C
BSNO (g/kWh)
Rate of NO reduction (%)
BMEP (bar)
0
5
10
15
20
25
30
20
0
-20
-40
-60
1.25
2.50
3.75
5.00

METANOL



Diesel
M50_40°C
M50_80°C
Diesel
M50_40°C
M50_80°C
Smoke (mg/m³)
Rate of Smoke reduction (%)
BMEP (bar)
1.25
2.50
3.75
5.00
0
5
10
15
20
25
50
0
-50
-100
-150
-200
-250