ReFuel 2021

International Workshop on the Application of Carbon-neutral Fuel

September 9, 2021

IASTEC
International association of sustainable Drivetrain and vehicle technology research (under foundation)

KSAE

ReFuel 2021 International Workshop on the Application of Carbon-neutral Fuel

Organized by

IASTEC
International association of sustainable Drivetrain and vehicle technology research (under foundation)

Supported by

KSAE

Thomas Koch,
Choongsik Bae (eds.)
and 5 authors

Preface

Dear colleagues,

It was great for us to host ReFuel 2021 as an on-line workshop.
We are pleased to bind and distribute the presentations by six world-renowned specialists who volunteered to contribute the active discussion on carbon-neutral future transportation. This workshop subject on carbon-neutral fuel was motivated by the position paper issued by IASTEC. This workshop enlightened scientific, reasonable, and balanced view points.
We believe the workshop provided the window for the global opinion exchange and ignited further discussions on the optimal passage to carbon neutrality. This workshop attracted more than 250 participants from 17 countries.
We appreciate contributors and hope the proceedings to be an useful literature.

We wish you all the best and health.

Organization Committee

Prof. Dr. sc. techn. Thomas Koch (General chair)
Prof. Dr. Choongsik Bae (Program chair)
Dr.-Ing. Amin Velji
Dr.-Ing. Olaf Toedter
Dr.-Ing. Heiko Kubach
Prof. Dr. Yasuo Moriyoshi
Dr. Wooyeong Kim

ReFuel 2021

International Workshop on the Application of Carbon-neutral Fuel
September 9, 2021· Free registration · Online meeting (Zoom)

ReFuel2021 will bring together academics, research, and industrial experts in the field of energy and environment mainly in the field of fuel processing and transportation.

This workshop aims to promote scientific information exchange and discussions between researchers, developers, and practitioners to achieve reasonable carbon-neutral energy supply chain for transportation with well-balanced view and analyses.

Committees

General Chair	Prof. Thomas Koch, Karlsruhe Institute of Technology (KIT), Germany
Program Chair	Prof. Choongsik Bae, Korea Advanced Inst. of Science and Tech. (KAIST), Korea

Program

	Session chair: Amin Velji (KIT)	
09:00 (CEST) 16:00 (FET)	Opening remark	Choongsik Bae (KAIST)
09:10	Perspectives of ReFuel	Thomas Koch (KIT, Germany)
09:35	Statistics and Physics of the Transition of Energy and Mobility Systems in Europe	Frank Atzler (TU Dresden, Germany)
	Session chair: Olaf Toedter (KIT)	
10:10	Japanese policy for carbon neutrality and e-fuel	Akiteru Maruta (Technova Inc., Japan)
10:35	E-fuel contribution via R&D in Finland	Martti Larmi (Aalto Univ., Finland)
11:00	An Efficient Way of e-fuel Production	Seok Ki Kim (KRICT: Korea Research Inst. of Chemical Tech.)
	Session chair: Choongsik Bae (KAIST)	
11:25	Mobile Carbon Capture (MCC)	Esam Hamad (Saudi Aramco, Saudi Arabia)
11: 50	Panel Discussion	
12:10 (CEST) 19:10 (FET)	Closing remark	Thomas Koch (KIT)

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ReFuel 2021

Perspectives of ReFuel

Thomas Koch
Karlsruhe Institute of Technology

About the speaker:

- Director of Institute of Internal Combustion Engines (IFKM) at KIT, Germany
- PhD at ETH Zurich
- Professional career at Daimler AG

Karlsruher Institut für Technologie

IFKM

Perspectives of reFuels?

A critical assessment of our discussions and suggestions

T. Koch + reFuels-Team

IASTEC
September 1st, 2021

Quelle: https://www.starobserver.org/image/1812/Earthrise1_Apollo8AndersWeigang_2048.jpg, NASA, Apollo 8, Bill Anders, Processing: Jim Weigang

Overview

Karlsruher Institut für Technologie

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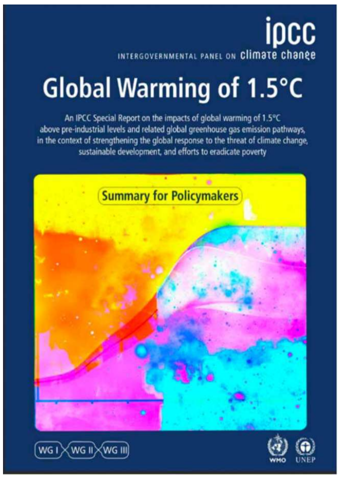
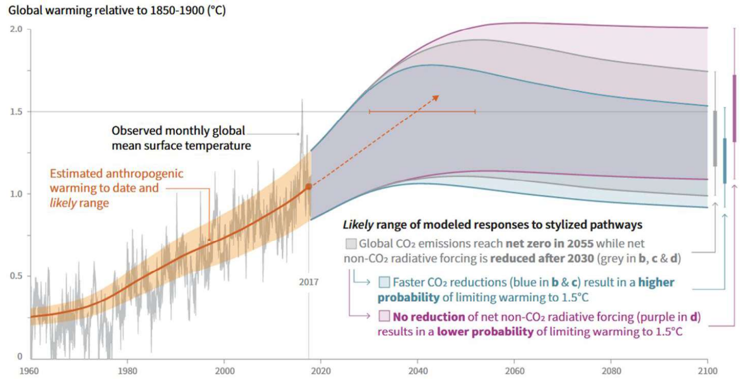
2018: IPCC report „Global warming of 1.5°C "

Karlsruher Institut für Technologie



https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf

A.1 Human activities are estimated to have caused approximately 1.0°C of global warming[5] above pre-industrial levels, with a *likely* range of 0.8°C to 1.2°C. Global warming is *likely* to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. (*high confidence*) (Figure SPM.1) {1.2}



Summary of A.1: Between 2030 and 2052, global warming will reach 1.5°C if it continues to increase at the current rate!

2018: Total CO_2 budget

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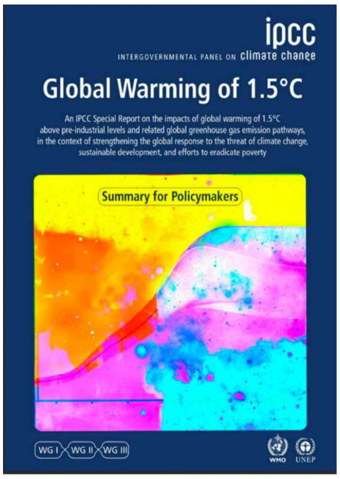


https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf

C.1.3 Limiting global warming requires limiting the total cumulative global anthropogenic emissions of CO_2 since the pre-industrial period, that is, staying within a total carbon budget (*high confidence*).[13] By the end of 2017, anthropogenic CO_2 emissions since the pre-industrial period are estimated to have reduced the total carbon budget for 1.5°C by approximately 2200 ± 320 $GtCO_2$ (*medium confidence*). The associated remaining budget is being depleted by current emissions of 42 ± 3 $GtCO_2$ per year (*high confidence*). The choice of the measure of global temperature affects the estimated remaining carbon budget. Using global mean surface air temperature, as in AR5, gives an estimate of the remaining carbon budget of 580 $GtCO_2$ for a 50% probability of limiting warming to 1.5°C, and 420 $GtCO_2$ for a 66% probability (*medium confidence*).[14] Alternatively, using GMST gives estimates of 770 and 570 $GtCO_2$, for 50% and 66% probabilities,[15] respectively (*medium confidence*). Uncertainties in the size of these estimated remaining carbon budgets are substantial and depend on several factors. Uncertainties in the climate response to CO_2 and non-CO_2 emissions contribute ±400 $GtCO_2$ and the level of historic warming contributes ±250 $GtCO_2$ (*medium confidence*). Potential additional carbon release from future permafrost thawing and methane release from wetlands would reduce budgets by up to 100 $GtCO_2$ over the course of this century and more thereafter (*medium confidence*). In addition, the level of non-CO_2 mitigation in the future could alter the remaining carbon budget by 250 $GtCO_2$ in either direction (*medium confidence*). {1.2.4, 2.2.2, 2.6.1, Table 2.2, Chapter 2 Supplementary Material}

Summary of C.1.3: Limiting total cumulative global anthropogenic CO_2 emissions is essential to limiting global warming. A budget of 420 Gt CO_2 has a 66% probability of limiting 1.5°C warming.

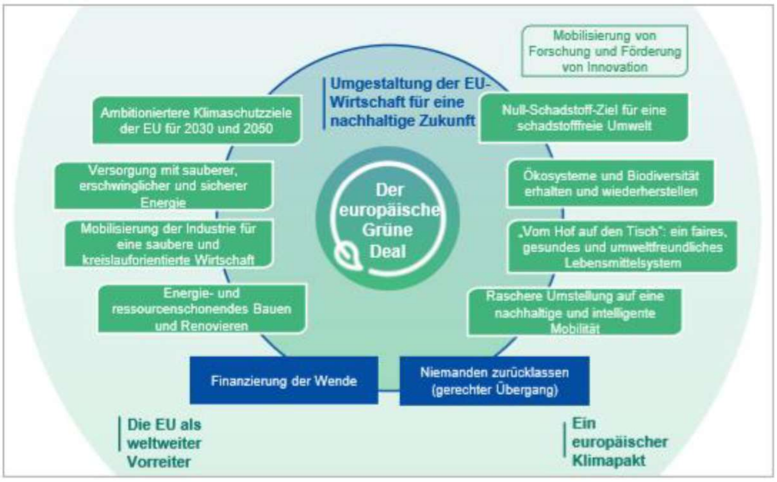
11.12.2019: EU Green Deal


EUROPÄISCHE KOMMISSION

MITTEILUNG DER KOMMISSION AN DAS EUROPÄISCHE PARLAMENT, DEN EUROPÄISCHEN RAT, DEN RAT, DEN EUROPÄISCHEN WIRTSCHAFTS- UND SOZIALAUSSCHUSS UND DEN AUSSCHUSS DER REGIONEN

Der europäische Grüne Deal

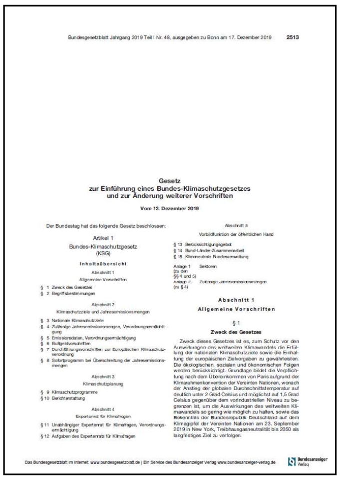
DE DE



Quelle: http://www.gesetze-im-internet.de/ksg/BJNR251310019.html

A key message of the EU Green Deal: by summer 2020, the Commission will present a plan to raise the greenhouse gas emissions reduction target to at least 50% by 2030 and a target of 55% compared to 1990.

17.12.2019: Federal Law of the BMU


Gesetz zur Einführung eines Bundes-Klimaschutzgesetzes und zur Änderung weiterer Vorschriften

Vom 12. Dezember 2019

Quelle: https://eur-lex.europa.eu

2520 Bundesgesetzblatt Jahrgang 2019 Teil I Nr. 48, ausgegeben zu Bonn am 17. Dezember 2019

Anlage 2
(zu § 4)

Zulässige Jahresemissionsmengen

Jahresemissionsmenge in Mio. Tonnen CO_2-Äquivalent	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Energiewirtschaft	280		257								175
Industrie	186	182	177	172	168	163	158	154	149	145	140
Gebäude	118	113	108	103	99	94	89	84	80	75	70
Verkehr	150	145	139	134	128	123	117	112	106	101	95
Landwirtschaft	70	68	67	66	65	64	63	61	60	59	58
Abfallwirtschaft und Sonstiges	9	9	8	8	7	7	7	6	6	5	5

Implementation in the form of the Federal Climate Protection Act envisions a reduction in CO_2 equivalent emissions from the transportation sector of approximately 37% in 2030 compared to 2020.

2018: IPCC report „Global warming of 1.5°C “

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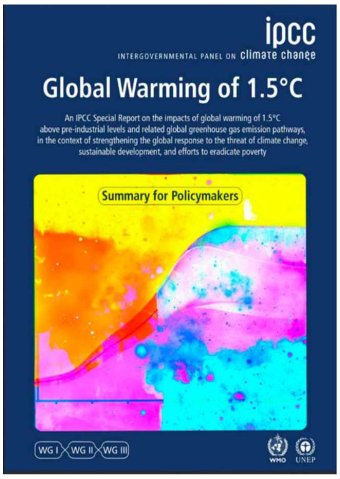

https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf

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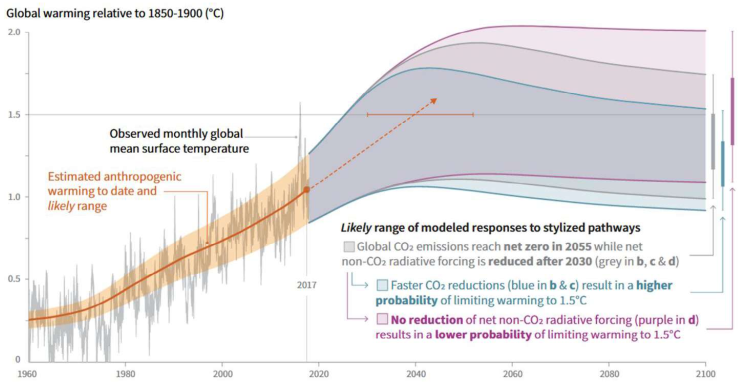

Summary of IPCC: A remaining CO_2-budget of 420 Gt CO_2 has a 66% probability of limiting 1.5°C warming.

2016: Renewable energy directive

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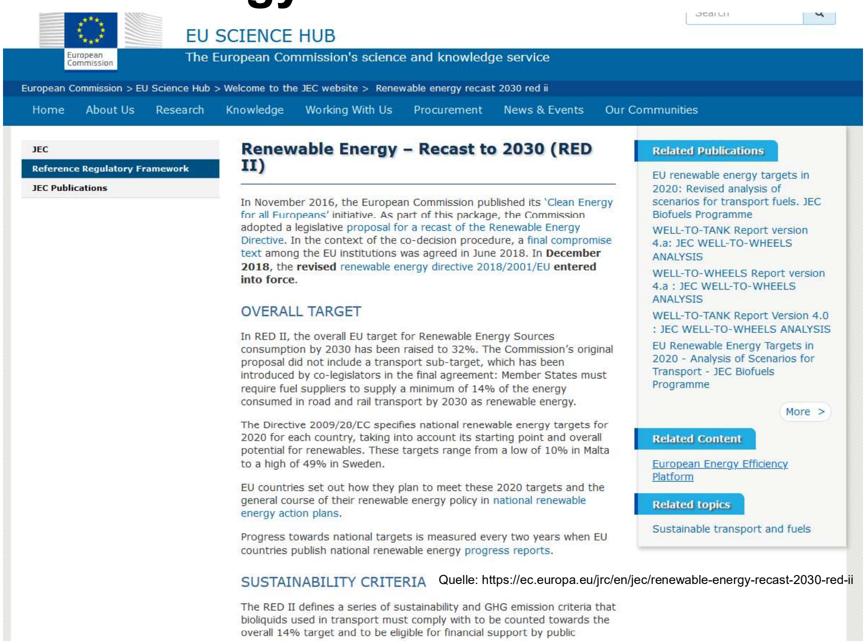

European Commission

EU SCIENCE HUB

The European Commission's science and knowledge service

European Commission > EU Science Hub > Welcome to the JEC website > Renewable energy recast 2030 red ii

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JEC
Reference Regulatory Framework
JEC Publications

Renewable Energy – Recast to 2030 (RED II)

In November 2016, the European Commission published its 'Clean Energy for all Europeans' initiative. As part of this package, the Commission adopted a legislative proposal for a recast of the Renewable Energy Directive. In the context of the co-decision procedure, a final compromise text among the EU institutions was agreed in June 2018. In **December 2018**, the **revised** renewable energy directive 2018/2001/EU **entered into force.**

OVERALL TARGET

In RED II, the overall EU target for Renewable Energy Sources consumption by 2030 has been raised to 32%. The Commission's original proposal did not include a transport sub-target, which has been introduced by co-legislators in the final agreement: Member States must require fuel suppliers to supply a minimum of 14% of the energy consumed in road and rail transport by 2030 as renewable energy.

The Directive 2009/20/CC specifies national renewable energy targets for 2020 for each country, taking into account its starting point and overall potential for renewables. These targets range from a low of 10% in Malta to a high of 49% in Sweden.

EU countries set out how they plan to meet these 2020 targets and the general course of their renewable energy policy in national renewable energy action plans.

Progress towards national targets is measured every two years when EU countries publish national renewable energy progress reports.

SUSTAINABILITY CRITERIA

The RED II defines a series of sustainability and GHG emission criteria that bioliquids used in transport must comply with to be counted towards the overall 14% target and to be eligible for financial support by public

Related Publications

EU renewable energy targets in 2020: Revised analysis of scenarios for transport fuels. JEC Biofuels Programme

WELL-TO-TANK Report version 4.a: JEC WELL-TO-WHEELS ANALYSIS

WELL-TO-WHEELS Report version 4.a : JEC WELL-TO-WHEELS ANALYSIS

WELL-TO-TANK Report Version 4.0 : JEC WELL-TO-WHEELS ANALYSIS

EU Renewable Energy Targets in 2020 - Analysis of Scenarios for Transport - JEC Biofuels Programme

More >

Related Content

European Energy Efficiency Platform

Related topics

Sustainable transport and fuels

Quelle: https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii

Overview

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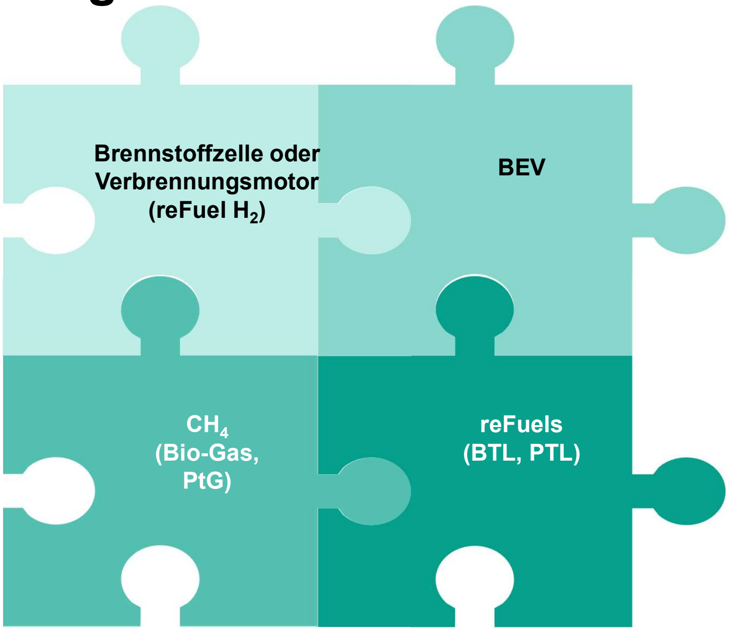
Technologieneutralität am KIT

Karlsruher Institut für Technologie



reFuels = bioFuels + eFuels

We at KIT believe in a multidimensional solution of the future, where different technology solutions co-exist.

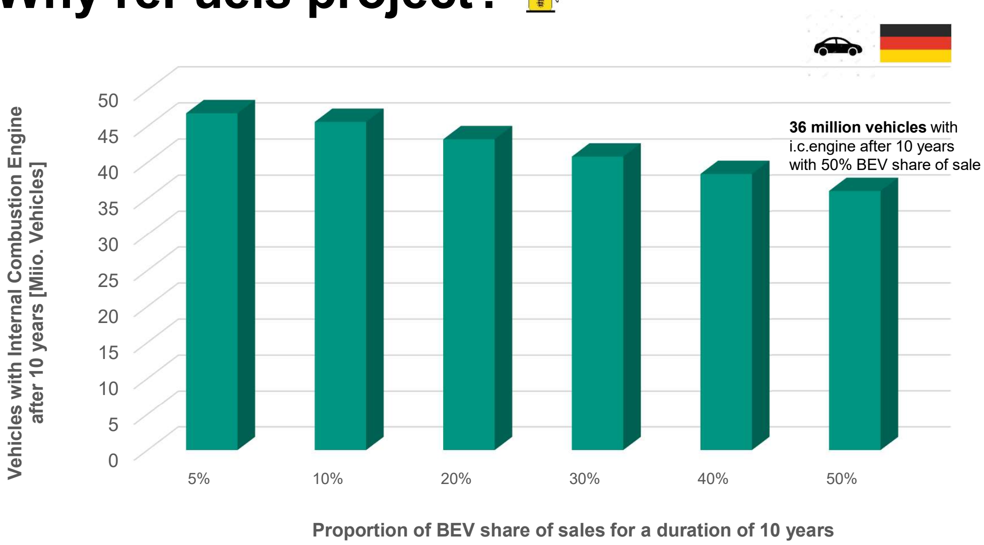
Project reFuels

Additional Information

- Industry partners and Baden-Württemberg invested 20.Mio € into refuels project.
- Ministry of transport of Baden-Württemberg is initiating political partner of refuels project.
- Project start was 1/2019.
- The first phase ends in 2021.
- More than 20 industry partners are involved with an unique contribution by automobile as well as mineral oil industry

The reFuels project is combining basic academic research questions with major environmental, industry as well as society issues.

Why reFuels project?

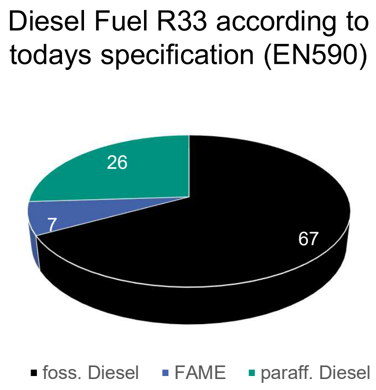


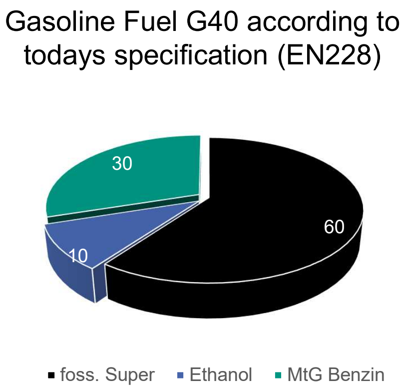
Boundary conditions and analysis

- The KBA Data from 2009 to 2019 act as reverence for the next decade.
- PHEV as well as HEV are also vehicles with internal combustion engine.
- Even with a 50% BEV share of sales in Germany, there would be more than one million new vehicles per year with internal combustion engine.
- BEV are a part of the solution, but not the only solution.

It is completely independent from political decisions and market response: most of total fleet vehicles will have an internal combustion engine in the year 2030.

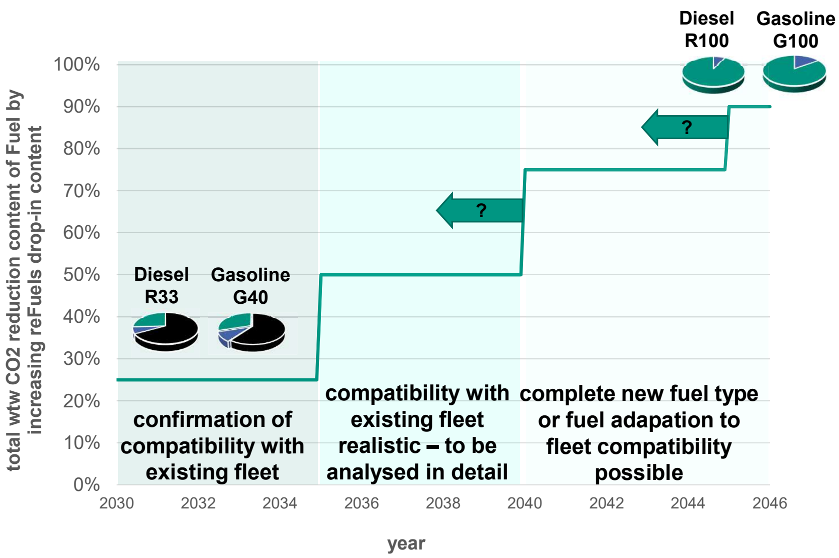
reFuels recommendation for 2030





A fuel CO_2-reduction potential of 25% can be realized within todays fleet compatible fuel specification. MTG or paraffinic diesel refuel can be produced via different routes (bioFuel, eFuel).

reFuels beyond 2030



Information

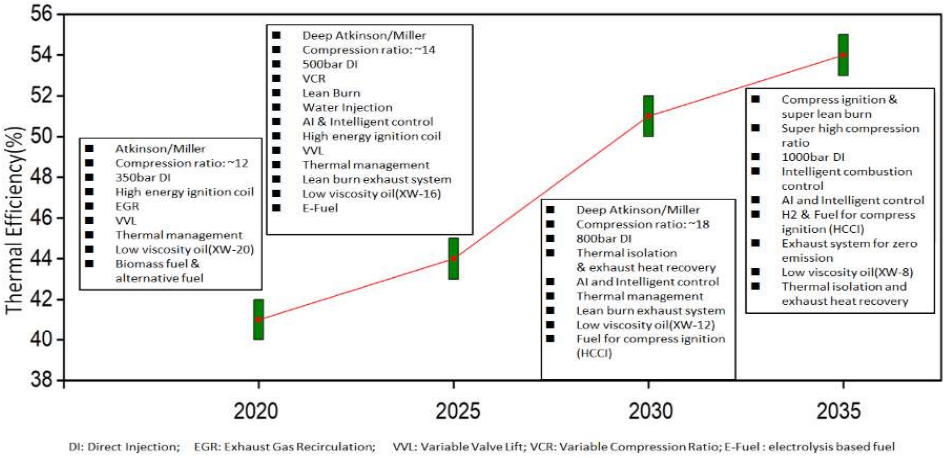
- Compatibility of Gasoline reFuel seems to be more challenging than diesel to enable fleet compatibility according to EN228/EN590.
- However, a compatibility with EN228/EN590 up to 50% CO_2 reduction potential by increased reFuels blending rate is realistic.
- **A mid-term >90% CO_2-reduction by fuels within the next 25 years together with additional technology development enables a reduction of CO_2-footprint of traffic sector by >95%.**

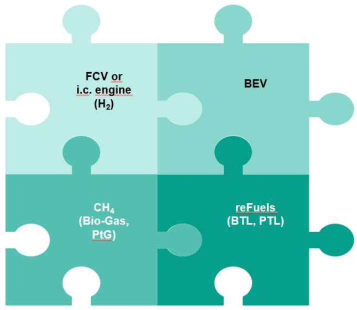
Even todays technology can be compatible with 100% refuel content. A mid-term 100% fleet compatible substitution of fossil fuels by reFuels is necessary. A step-by-step increase of the drop-in rate is recommended.

China

Information

- China has published a long term strategy with internal combustion engine technology.
- There is not only one solution for the future:





China is following the refuels path.

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WKM: German scientific association: first and second position paper

Karlsruher Institut für Technologie

WKM

Wissenschaftliche Gesellschaft für Kraftfahrzeug- und Motorentechnik e.V. (WKM)

Die WKM e.V. ist die Vereinigung von Professoren deutscher, österreichischer und schweizerischer Universitäten, die als Institutsleiter oder als Leiter von Fachgebieten oder Lehrstühlen auf dem Gebiet der Kraftfahrzeug- und/oder Motorentechnik tätig sind oder waren.

Zweck der WKM ist die Förderung von Wissenschaft und Forschung, von wissenschaftlicher Lehre, Studium und Heranbildung des wissenschaftlichen Nachwuchses auf dem Gebiet der Kraftfahrzeug- und Motorentechnik.

Nach intensiven Diskussionen insbesondere über dieselmotorische Emissionsfragestellungen und einer Bewertung dieses Sachverhaltes im Jahr 2017 hat die WKM e.V. dieses zweite Positionspapier im Rahmen der aktuellen Bestrebungen zur Erarbeitung einer neuen „CO_2-Gesetzgebung im Verkehrssektor" ausgearbeitet.

Drittes WKM Positionspapier

März 2021

Technische, regulatorische und gesellschaftliche Herausforderungen bei der Realisierung einer CO_2-neutralen Antriebstechnik für PKW und Nutzfahrzeuge in den nächsten Jahrzehnten

WKM

Wissenschaftliche Gesellschaft für Kraftfahrzeug- und Motorentechnik e.V.

Key messages:

We hardly save CO_2 with BEV transfer within the next decade!

5. Mit dem aktuellen deutschen Bundesklimaschutzgesetz wird das Reduzierungspotenzial nicht ausgeschöpft. Die Empfehlungen des IPCC (intergovernmental panel of climate change) nach einer raschen CO_2-Emissionsreduzierung werden nicht bestmöglich umgesetzt, und eine unnötige Belastung des CO_2 - Restbudgets ist die Folge [12–15].

2. Die Frage der ganzjährigen Bereitstellung CO_2-schonender elektrischer Energie verbleibt über Jahrzehnte eine große Herausforderung.
   a. Daher wird die Umstellung auf batterieelektrische Fahrzeuge im PKW-Markt frühestens 2035 einen entscheidenden Anteil an der CO_2-Emissionsreduzierung tragen [13].

3. Die WKM kritisiert allerdings, dass durch die derzeitig getrennte Betrachtung der Sektoren keine ganzheitlich optimale Absenkung der CO_2-Emissionen erreicht wird [26]. Vielmehr führt die Regulierung zu einer singulären Optimierung der einzelnen Sektorenemissionen. Dadurch werden große ganzheitliche CO_2-Potentiale nicht genutzt, falsche Stoppsignale für die Technologieentwicklung gesetzt und wichtige Technologien nicht betrachtet. So ist auf der Basis der geplanten Regulierung zukünftig nur das batterieunterstützte (BEV/PHEV) oder das H_2-getriebene Fahrzeug (FCV, VM) ohne CO_2-Strafzahlungen verkäuflich, obwohl mit reFuels betriebene Fahrzeuge vergleichbare Umweltvorteile aufweisen [27].

IASTEC

Karlsruher Institut für Technologie

https://iastec.org

IASTEC
international association of sustainable drivetrain and vehicle technology research

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IASTEC – The International Association of Sustainable Drivetrain and Vehicle Technology Research

The International Association of Sustainable Drivetrain and Vehicle Technology Research, IASTEC (in the process of founding) is an international association of professors and researchers worldwide working on vehicle and drivetrain research at famous universities. The purpose of IASTEC is to promote science, research and teaching in the field of vehicle and drivetrain technology.

08.09.2021 Are low carbon reFuels a solution – a reFuels assessment

Institute of internal combustion engine research
Prof. Dr. sc. techn. Thomas Koch
IFKM

ZAMM Publication

The averaging bias - a standard miscalculation, which extensively underestimates real CO_2 emissions

Thomas Koch*[1] | Thomas Böhlke[2]

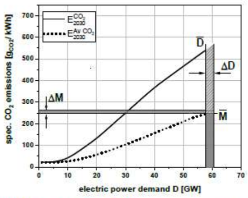


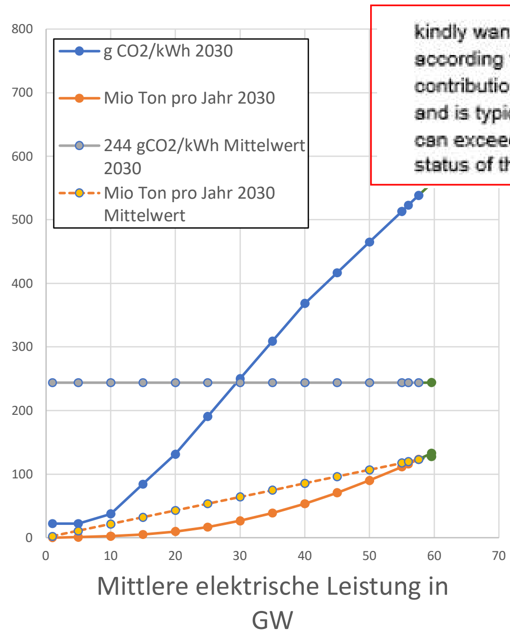
FIGURE 6 Graphical illustration of equation (50) and (51). Please note that the depicted areas represent $\bar{M}(\bar{D})\Delta\bar{D}$ and $\bar{D}\Delta M(\bar{D}, \Delta D)$.

Letter to EU-commission

IASTEC SECTION EUROPE

kindly want to inform you, that the correct calculus is $\Delta F_{CO2} = M \cdot \Delta D + \Delta M \cdot D$ (eq.2) [3], according to the fundamental theorem of Leibniz from the 17th century. The additional contribution of the second summand $\Delta M \cdot D$ depends on the status of the electricity system and is typically omitted very often. Please kindly note that the real CO_2 emissions (eq.2) can exceed those of eq. 1 easily by more than factor 2, depending on the year and the status of the energy system!

The avaraging bias



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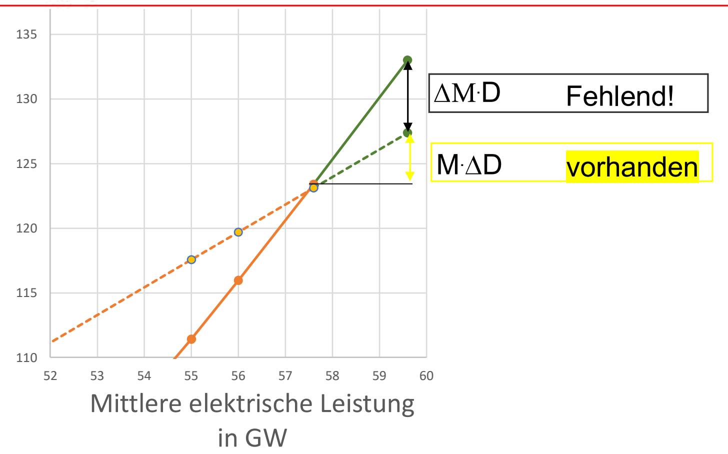
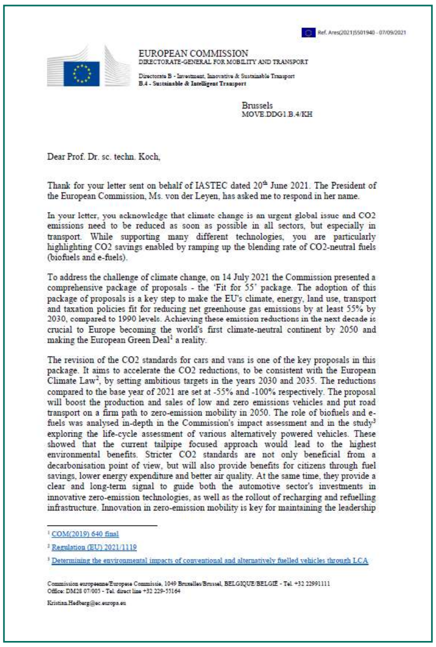


07.09.2021: Response of EU-commission



Ref. Ares(2021)5501940 - 07/09/2021

EUROPEAN COMMISSION
DIRECTORATE-GENERAL FOR MOBILITY AND TRANSPORT

Directorate B - Investment, Innovative & Sustainable Transport
B.4 - Sustainable & Intelligent Transport

Brussels
MOVE.DDG1.B.4/KH

Dear Prof. Dr. sc. techn. Koch,

Thank for your letter sent on behalf of IASTEC dated 20th June 2021. The President of the European Commission, Ms. von der Leyen, has asked me to respond in her name.

In your letter, you acknowledge that climate change is an urgent global issue and CO2 emissions need to be reduced as soon as possible in all sectors, but especially in transport. While supporting many different technologies, you are particularly highlighting CO2 savings enabled by ramping up the blending rate of CO2-neutral fuels (biofuels and e-fuels).

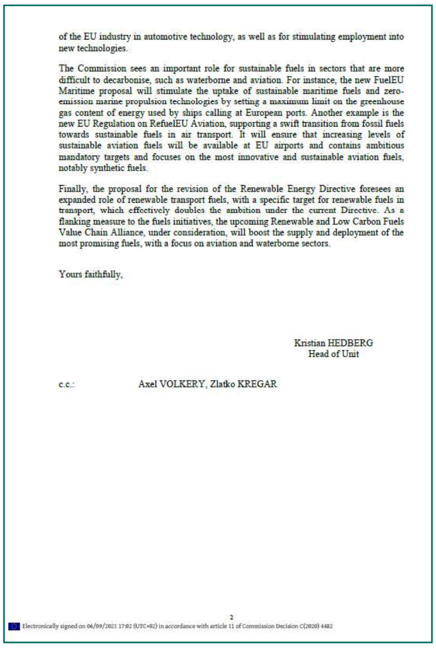
To address the challenge of climate change, on 14 July 2021 the Commission presented a comprehensive package of proposals - the 'Fit for 55' package. The adoption of this package of proposals is a key step to make the EU's climate, energy, land use, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels. Achieving these emission reductions in the next decade is crucial to Europe becoming the world's first climate-neutral continent by 2050 and making the European Green Deal[1] a reality.

The revision of the CO2 standards for cars and vans is one of the key proposals in this package. It aims to accelerate the CO2 reductions, to be consistent with the European Climate Law[2], by setting ambitious targets in the years 2030 and 2035. The reductions compared to the base year of 2021 are set at -55% and -100% respectively. The proposal will boost the production and sales of low and zero emissions vehicles and put road transport on a firm path to zero-emission mobility in 2050. The role of biofuels and e-fuels was analysed in-depth in the Commission's impact assessment and in the study[3] exploring the life-cycle assessment of various alternatively powered vehicles. These showed that the current tailpipe focused approach would lead to the highest environmental benefits. Stricter CO2 standards are not only beneficial from a decarbonisation point of view, but will also provide benefits for citizens through fuel savings, lower energy expenditure and better air quality. At the same time, they provide a clear and long-term signal to guide both the automotive sector's investments in innovative zero-emission technologies, as well as the rollout of recharging and refuelling infrastructure. Innovation in zero-emission mobility is key for maintaining the leadership

[1] COM(2019) 640 final
[2] Regulation (EU) 2021/1119
[3] Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA

Commission europeenne/Europese Commissie, 1049 Bruxelles/Brussel, BELGIQUE/BELGIË - Tel. +32 22991111
Office: DM28 07/005 - Tel. direct line +32 229-55164

Kristian.Hedberg@ec.europa.eu



of the EU industry in automotive technology, as well as for stimulating employment into new technologies.

The Commission sees an important role for sustainable fuels in sectors that are more difficult to decarbonise, such as waterborne and aviation. For instance, the new FuelEU Maritime proposal will stimulate the uptake of sustainable maritime fuels and zero-emission marine propulsion technologies by setting a maximum limit on the greenhouse gas content of energy used by ships calling at European ports. Another example is the new EU Regulation on RefuelEU Aviation, supporting a swift transition from fossil fuels towards sustainable fuels in air transport. It will ensure that increasing levels of sustainable aviation fuels will be available at EU airports and contains ambitious mandatory targets and focuses on the most innovative and sustainable aviation fuels, notably synthetic fuels.

Finally, the proposal for the revision of the Renewable Energy Directive foresees an expanded role of renewable transport fuels, with a specific target for renewable fuels in transport, which effectively doubles the ambition under the current Directive. As a flanking measure to the fuels initiatives, the upcoming Renewable and Low Carbon Fuels Value Chain Alliance, under consideration, will boost the supply and deployment of the most promising fuels, with a focus on aviation and waterborne sectors.

Yours faithfully,

Kristian HEDBERG
Head of Unit

c.c.: Axel VOLKERY, Zlatko KREGAR

2

Electronically signed on 06/09/2021 17:02 (UTC+02) in accordance with article 11 of Commission Decision C(2020) 4482

07.09.2021: Response of EU-commission

The revision of the CO2 standards for cars and vans is one of the key proposals in this package. It aims to accelerate the CO2 reductions, to be consistent with the European Climate Law[2], by setting ambitious targets in the years 2030 and 2035. The reductions compared to the base year of 2021 are set at -55% and -100% respectively. The proposal will boost the production and sales of low and zero emissions vehicles and put road transport on a firm path to zero-emission mobility in 2050. The role of biofuels and e-fuels was analysed in-depth in the Commission's impact assessment and in the study[3] exploring the life-cycle assessment of various alternatively powered vehicles. These showed that the current tailpipe focused approach would lead to the highest environmental benefits. Stricter CO2 standards are not only beneficial from a

Overview

1. IPCC Guideline
2. Why reFuels?
3. Why IASTEC?
4. Critical discussion?
5. Summary

Critical discussion of our argumentation

Karlsruher Institut für Technologie

- A couple of very critical and partly inaccaptable attacks towards our position paper and ZAMM publication were even embarassing! Our petition to precisely define the CO_2 impact of electrical consumers is very strong, as we defined a mathematical axiom, which is valid for a mixed partly renewable partly non-renewable electricity system in general!
- What we should further improve:
- We often argue, that the existing fleet requires reFuels. This leads to the opinion, that reFuels are only necessary for a interim-period.

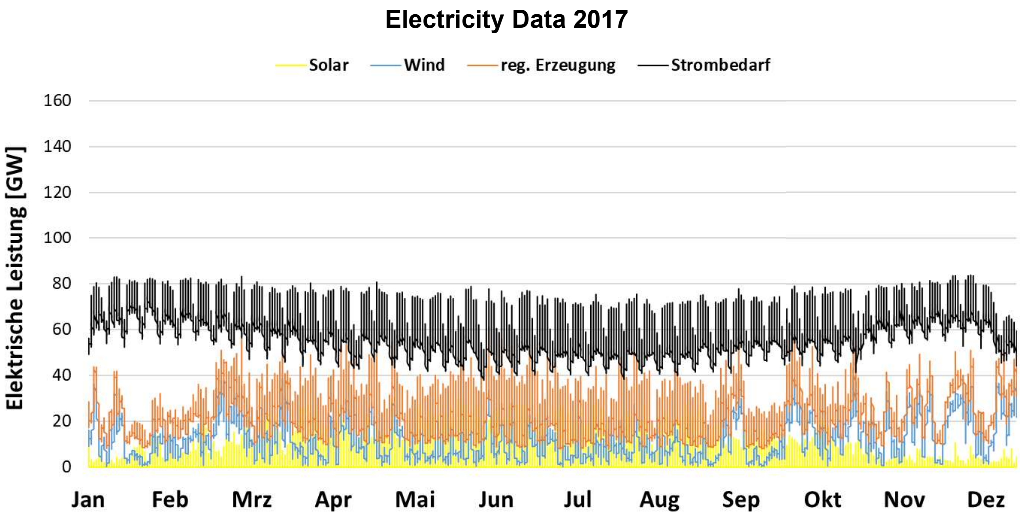
Critical discussion of our argumentation

Karlsruher Institut für Technologie

- We often argue, that it is impossible to quickly build up infrastructure and CO_2 free electricity. This argument is also transferred into: -> “but after a time period reFuels don´t make sense any more and are not required”
- We shouldn´t emphasize arguments leading to difficulties of raw material availability (copper, nickel), as we have the impression, that production difficulties are not seen a political issue.
- The political postulation to reduce individual pesscars from 450 to 150 cars/1000 inhabitants German is pushed. We should not argue with cost or social unequities (poor people not able).
- We need to emphasize the negative impact on tax, jobs, environment, political stability.

Thank you for your attention

Reference electricity demand for analysis



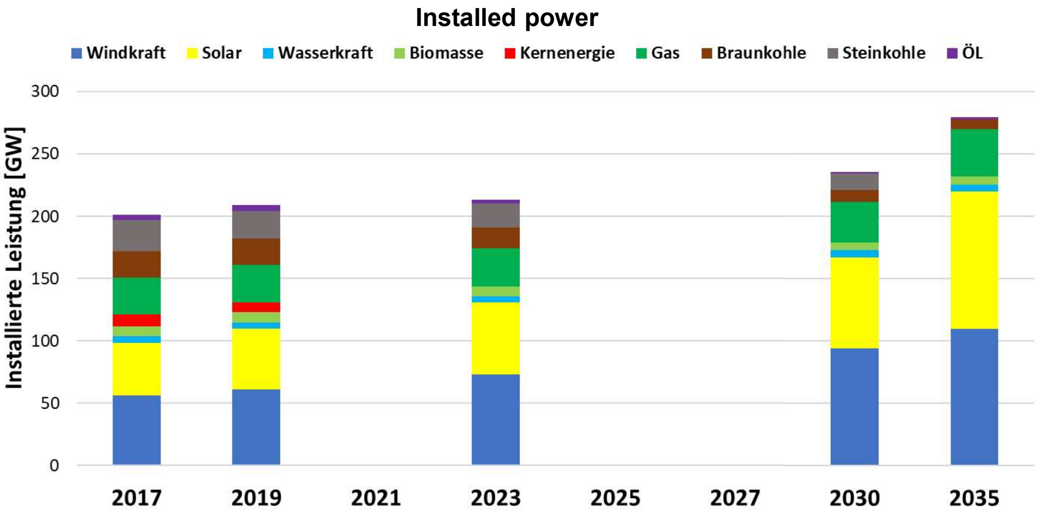
Quelle: energy-charts.info

Boundary conditions of analysis

- The analysis is based on hourly-resolved real-time data from the network operators from 2017
- The balance limit is Germany.
- Balance flows across system boundaries (import and export flows) are considered.
- A comparison with the integral parameters of the year 2019 shows the general transferability of the approach.

The expansion of wind power and photovoltaic plants is making an increasingly effective contribution to Germany's overall energy balance. 2017 was used as the reference year for the analyses.

Expansion potential of wind power and photovoltaics



Quelle: Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen, „Genehmigung des Szenariorahmens 2019-2030", „Genehmigung des Szenariorahmens 2021-2025",

Explanation „installed power“

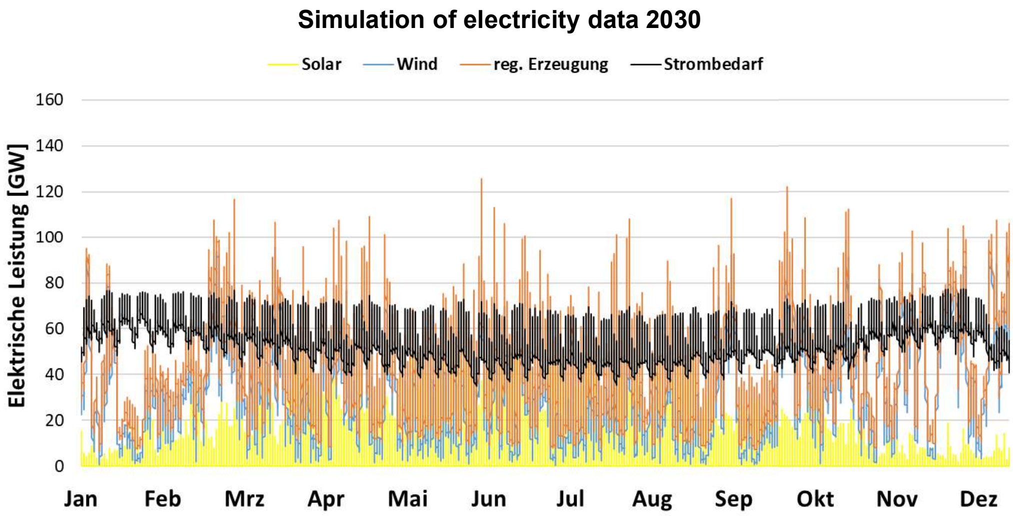
- The expansion of installed capacity, primarily of wind power and photovoltaics, is based on the analysis of the Federal Network Agency of 15.06.2018 and 26.07.2020.
- The following increase in installed capacity is forecast:

Period	Wind power	Photo-voltaic
2030 vs. 2017	69%	72%
2035 vs. 2017	96%	160%

- The proportion of installed capacity accounted for by "renewables" is approx. 76% in 2030 and approx. 83% in 2035

Expansion of wind power and photovoltaics will increase strongly in the coming years. The expansion targets assumed in the selected scenario framework are ambitious and are taken as given.

Hourly-resolved simulation 2030



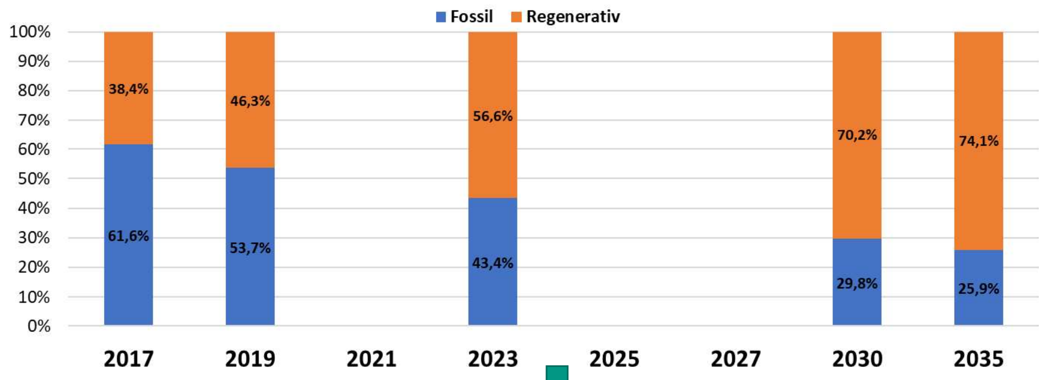
Explanation „analysis 2030“

- The analysis shown on the left is a combination of 2017 real-time data and installed capacity build-out data.
- Wind is analyzed separately onshore and offshore, but listed together in the figure.
- Also in this representation on the left is the basis
  - 0 BEV Scenario
  - Expansion of heat pumps according to scenario specifications.

The sum of photovoltaics, wind power, hydropower and biomass is summarized as "non-fossil generation". The non-fossil minimum / peak sum capacity is approx. 7/126 GW in 2030.

Balance sheet analysis

Integral share of electricity production



Quelle: energy-charts.info, Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen, „Genehmigung des Szenariorahmens 2019-2030", „Genehmigung des Szenariorahmens 2021-2025"

Explanation CO_2 footprint

- The balance (left) results from the scenario framework.

The CO_2 footprints are:

Technology	g_{CO_2} / kWh
Hydropower	23
Wind power	9
Photovoltaics	50
Biomass	70
Gas	499
Brown coal	1075
Hard coal	830

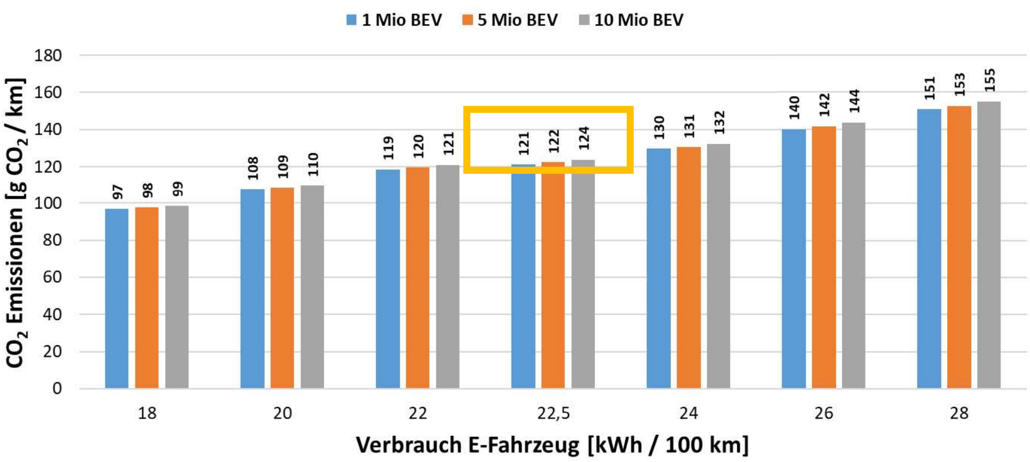
Quelle:Fraunhofer ISE, www.pv-fakten.de

	2017	2019	2023	2030	2035
Footprint of electrical energy g_{CO_2} / kWh	412	363	370	244	198

A footprint of 198 g_{CO_2}/kWh leads to a theoretical value of 45 g_{CO_2}/km for 22.5 kWh / 100km (BEV).

BEV CO_2 emissions 2030

CO_2 emissions 2030



Explanation „spec. CO_2 emissions"

- For example, for 10 million BEV vehicles, this results in 17.3 million tons of additional CO_2 emissions at 14.000 km/year per vehicle and 22.5 kWh / 100 km.
- The left illustration shows a different electrical energy demand.
- Of course, higher electrical energy demand also increases the CO_2 footprint.

For the electric energy demand of 22.5 kWh / 100 km, the CO_2 emission in 2030 is between 121 and 124 g CO_2 / km depending on the number of vehicles!

Questions, answers, and comments

Q. The present situation in Germany regarding to the change ratio of electrical energy and push of regeneration energy will not be enough to drive the electrical vehicles in the future. Is that the basic message?

A. Basic message is the CO2 impact to the electricity sector is significantly higher than assumed. According to German renewable energy law, photovoltaic and wind turbine has low impact and were preferred. However, the CO2 impacts increased as the electricity demand is increased. Question is how the additional electricity demand will interact with the CO2 impacts. Political report only used multiplication of the average CO2 emission value times electricity demand, but the CO2 emission value also interacts with the electrical demand, two times more than the average when the electrical demand is high.

Q. According the different fuel blend from your PowerPoint, 33% e-fuel for diesel, 40% e-fuel for gasoline to 50% and towards 100%. What are the future components of R100 and G100 when you are aiming for 100%?

A. Importance is the path how we will produce the paraffine diesel and methanol. Different path to produce paraffine diesel and methanol such as biomass, electrolysis, gas-shifting, but Ethanol and Methanol are the major components for Gasoline and Paraffine Diesel is the major component for the diesel.

Q. But in that case, we need something with high density because we will suffer from too little benzene quantity if we increase the paraffine portion.

A. Adding additives is required.

C. Even if we provide all the electricity with renewable energy, there is another problem with how we store the energy because electricity is not storable. Liquid fuel is a perfect way to store energy and transport compare to the battery.

Statistics and physics of the transition of energy and mobility systems in Europe

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Frank Atzler

TU Dresden

About the speaker:

- Professor of Combustion Engines and Power Train Systems in TU Dresden, Germany
- PhD at University of Leeds
- Professional career at IVECO and Continental Automotive GmbH

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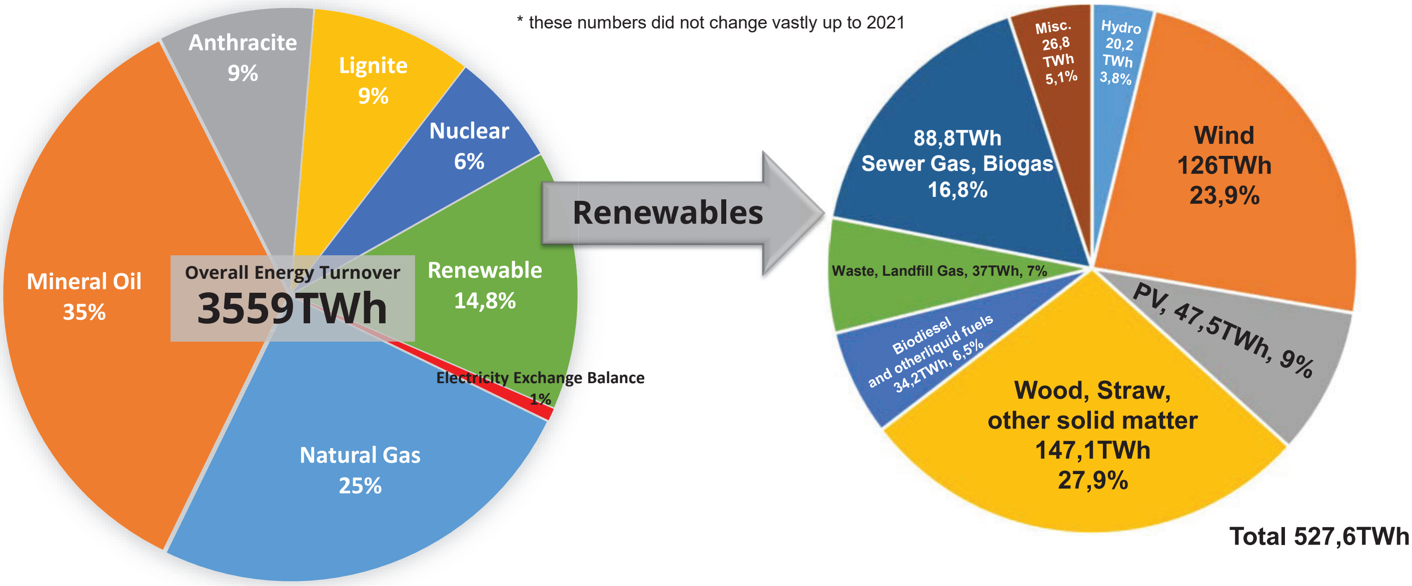
und Antriebssysteme

The Transition of Energy and Mobility Systems

International Workshop on the Application of Carbon-neutral Fuel, September 9th, 2021

Prof. Dr. Ing. Frank Atzler

Primary Energy Consumption in Germany
Source: Arbeitsgemeinschaft Energiebilanzen, 2019* https://www.ag-energiebilanzen.de/



1) only 14,8% (2020: 16,8%) of the overall primary energy consumtion are covered by renewables
2) only 5% of the overall primary energy consumtion are supplied by wind and photovoltaics
3) Germany/Europe will always be dependent on energy imports, currently nearly 70% of primary energy*
4) Which energy carrier is suitable for long distance transport über weite Strecken? Electricity, H_2, liquid reFuels?

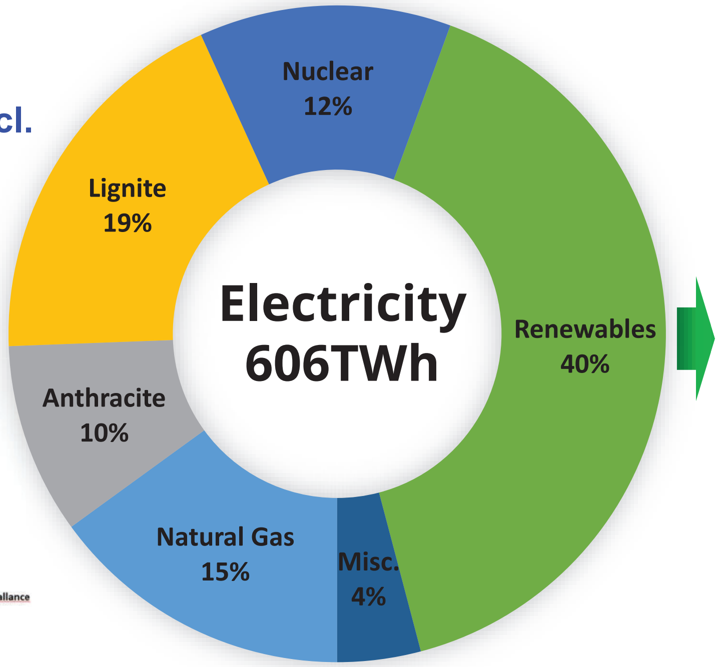
*Quelle: Statistisches Bundesamt

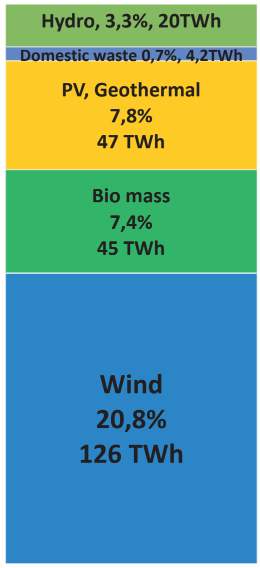
Electricity Generation in Germany 2019

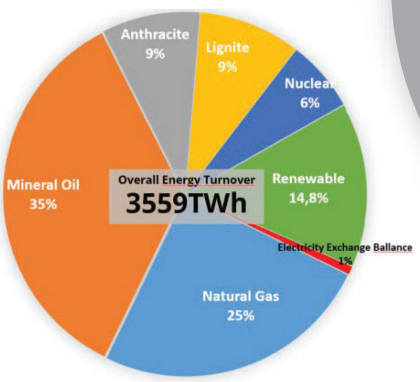
Source: Arbeitsgemeinschaft Energiebilanzen, Stand 2019 https://www.ag-energiebilanzen.de/

How will we replace 31% of electricity generation (Lignite + Nuclear), resp. 41% incl. Anthracite………..?

Import of green energy carriers !

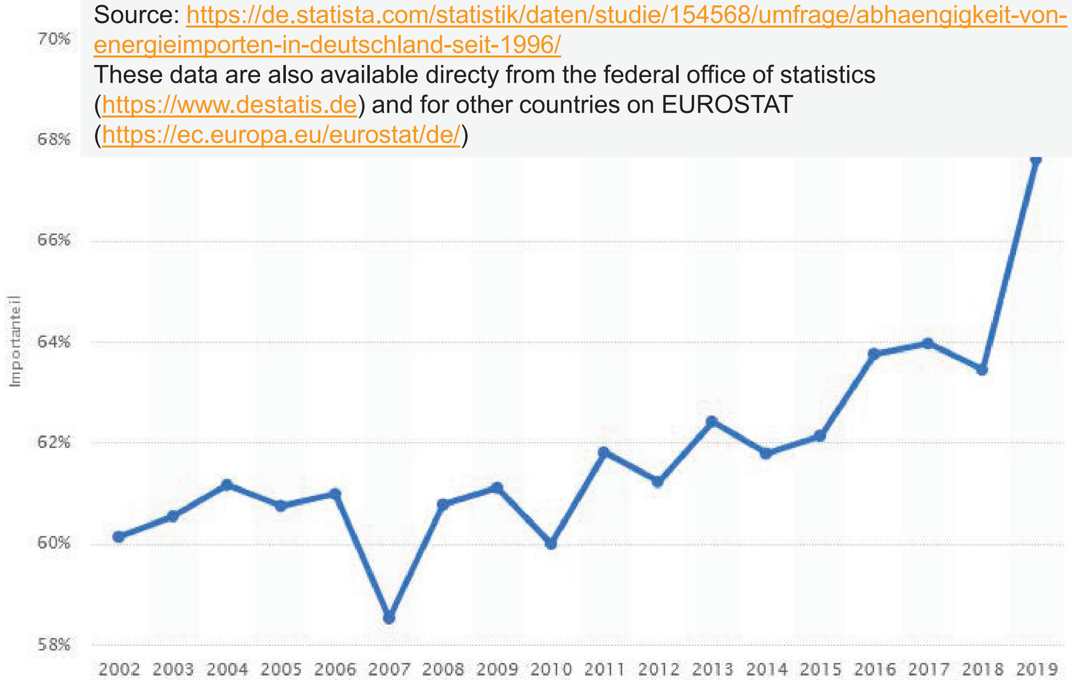






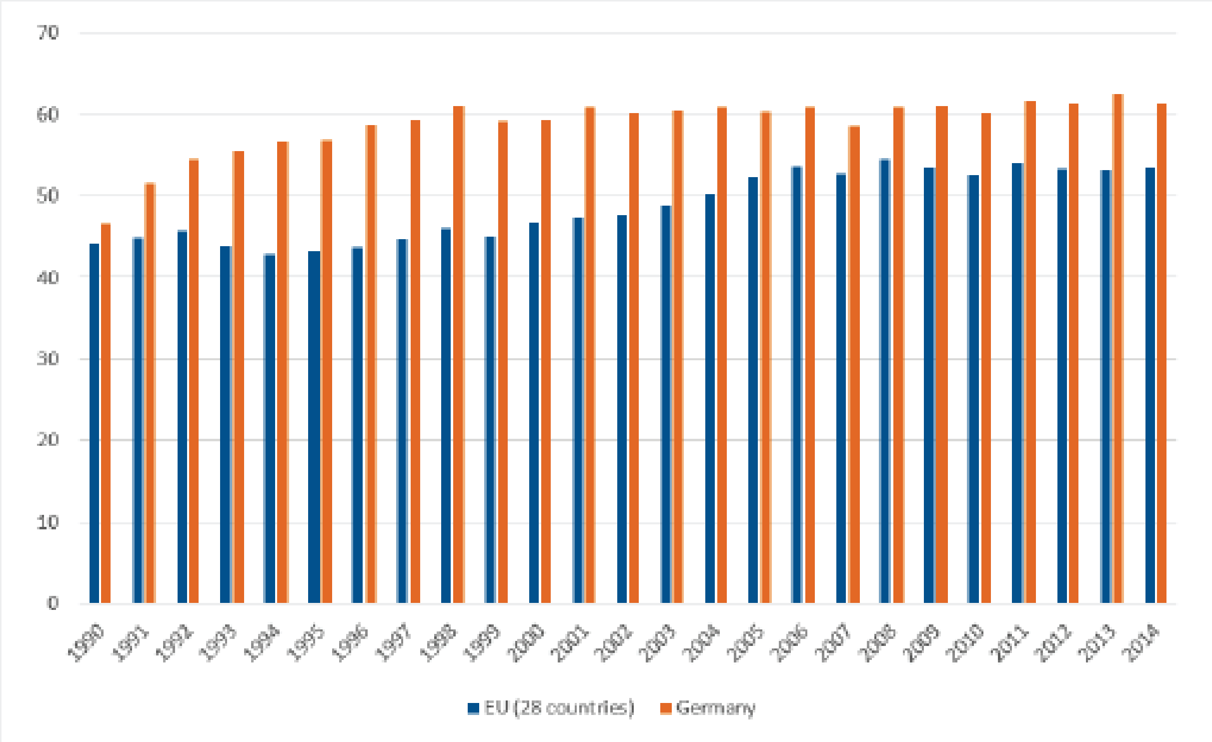
Energy Import to Germany, Share of Primary Energy Demand

Source: https://de.statista.com/statistik/daten/studie/154568/umfrage/abhaengigkeit-von-energieimporten-in-deutschland-seit-1996/
These data are also available directy from the federal office of statistics (https://www.destatis.de) and for other countries on EUROSTAT (https://ec.europa.eu/eurostat/de/)



Energy imports should be made in a form that can be stored. This is important to cover import and supply fluctuations of any kind. A self-sufficient energy supply will hardly be possible in Europe.

Energy import to Europe/Germany 1990 - 2014
Source: Eurostat



Electricity production: wind energy
Self-sufficient Germany?

Number of wind turbines in Germany 2018: **30518** → **126TWh yield in 2019**
Sources: Bundesverband Windenergie, Umweltbundesamt, Bundesnetzagentur + www.smard.de

Basis: Primary Energy Consumption in Germany 2021, estimate app. 3500TWh					
Zahl der Anlagen	Full Load Power	Overall Power	Load Factor	Energy harvest	Fraction of 3500TWh
n	MW	MW		TWh/a	%
60000	3	180000	0,23	363	10,4%
	Turbines per Windpark	Surface of Gemany	Surface Square per Park	Distance between Windparks	
	-	km2	km2	km	
60000	10	357000	59,5	**7 to 8km**	

→ „each village its own wind park“ → citizen participation? → nevertheless scenarios with 60000 wind turbines are rather unlikely.

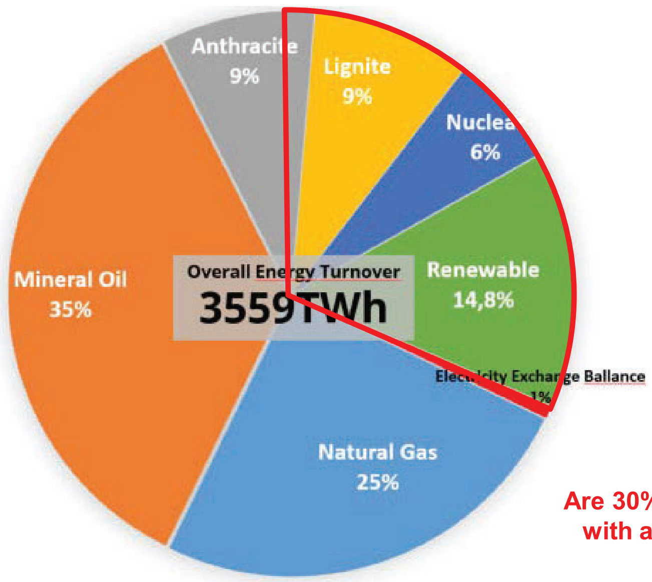
Sources: Load Factor: http://windmonitor.iee.fraunhofer.de/windmonitor_de/3_Onshore/5_betriebsergebnisse/1_volllaststunden/, own calculations, Atzler, TU Dresden, Stat. Bundesamt 2019

Electricity production: photo voltaics
Self-sufficient Germany?

Germany, km2	Germany, m2	Average Yield in kWh/m2/a	Total yield for all of the surface, in kWh/a	Conversion kWh in TWh, /10^9		
357000	3,57E+11	1100	3,927E+14	392700		
Total of sealed surfaces in Germany		5%	Source: IGR Monitor			
Populated area		12,50%				
theoretical yield from 1% of the surface, in TWh:				3927		
Overall Primary Energy Consumption, est. for 2021				3500		
On 3% of Germany's surface enough energy could be harvested theoretically to produce Methanol at an efficiency including all losses of 33%						
(Methanol production from electrolysed Hydrogen is rated at an efficiency of app. 50%)						
Methanol is a chemical energy storage for darkness and dead calm (no wind at all) as well as for winter, and engines can be run with it CO2 neutrally						
3% of Germany's surface, km2:		10710	10710 PV-Parks, 1km2 each per surface unit of X in km2:			33,33
			Distance between PV parks 5,75km (6 x 6 = 36km2)			

Sources: own calculations, Atzler, TU Dresden,
Fraunhofer ISE, Stromgestehungskosten erneuerbare Energien, Juni 2021, energy yield Germany 950 (north) to 1300kWh/m²/a (south) → mean 1125

Primary Energy Consumption in Germany
Source: Arbeitsgemeinschaft Energiebilanzen, 2019* https://www.ag-energiebilanzen.de/



Are 30% renewables produced nationally realistic with administrative rules and citizen protests?

1) only 14,8% (2020: 16,8%) of the overall primary energy consumtion are covered by renewables

2) only 5% of the overall primary energy consumtion are supplied by wind and photovoltaics

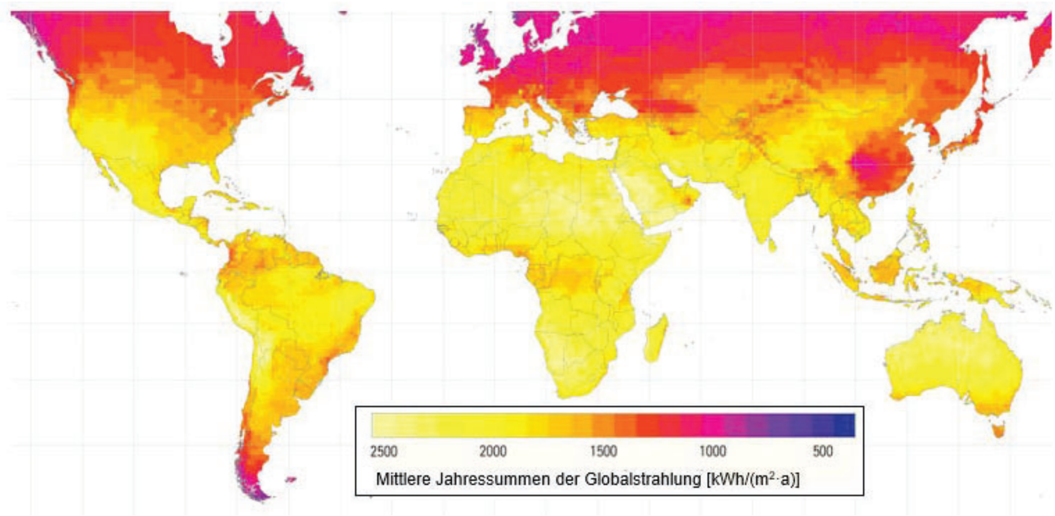
3) Germany/Europe will always be dependent on energy imports, currently nearly 70% of primary energy*

4) Which energy carrier is suitable for long distance transport über weite Strecken? Electricity, H_2, liquid reFuels?

*Quelle: Statistisches Bundesamt

Photovoltaics, world map of sun energy

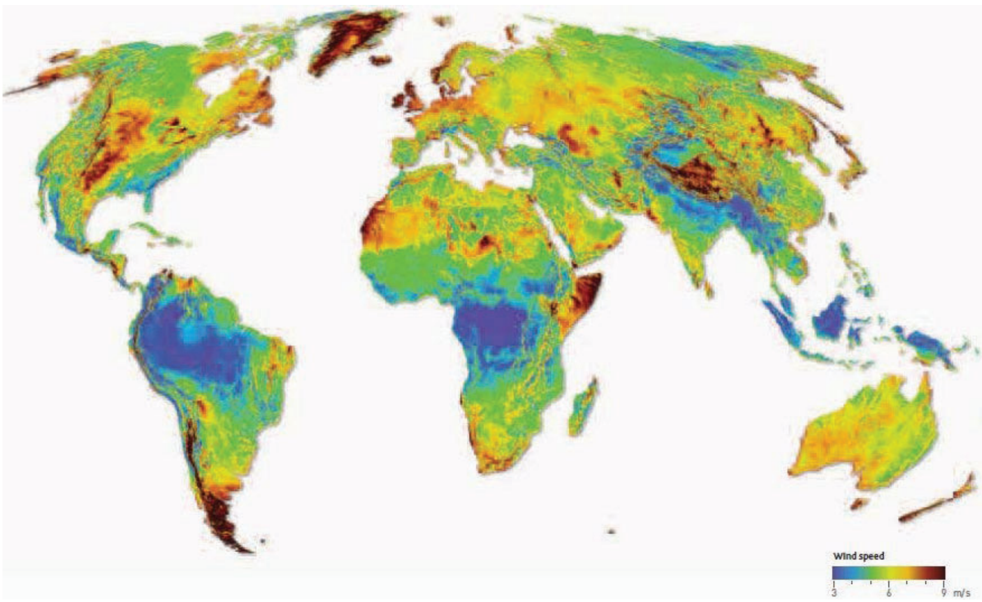
Konrad Mertens, "Photovoltaik - Lehrbuch zu Grundlagen, Technologie und Praxis", Hanser Verlag, 2020



Average yield in Germany app. 1100kWh/m²/a
Yield in the „sun belt“ of the world: up to 2500kWh/m²/a → Factor 2,27 → economical production!
Geopolitical questions: Spain, Portugal, South of Italy, Greece → within the EU
Turkey, Australia, Brasil, Chile, Argentine ? Regions of Africa?
USA, China and Indien are assumed to use their ressources themselves

Wind map of the world, wind speed 80m above ground

https://crushtymks.com/wind-power/1607-what-about-the-worlds-wind-resources.html



Areas with elevated wind potential:
near coastal regionen of Europe (Atlantic, north sea, baltic sea), Russia, Alaska, Canada, Patagonia, Greenland, South Africa and Australia, North-West-Africa, Central USA

Germany: ca. 7m/s
Potential areas: 9 m/s

Energy logistics across the world
The challenge of volumetric Energy Density

- **Hydrogen H_2:** Liquid at -253 °C: 71 kg/m³ → **2343 kWh/m³ = 2,34 kWh/Liter**

  Liquefaction consumes some 25 - 40% of the energy content of H_2 → 1,4 – 1,8 kWh_{eff}

  gaseous, 700bar: 43 kg/m³ → **1419 kWh/m³ = 1,42 kWh/Liter**

  Compression to 700bar consumes app. 15% of the energy content of H_2 → 1,2kWh_{eff}

- **Green Fuels synthesised from H_2 und recycling carbon (CO_2)**

  Example: **Methanol:** 790 kg/m³ → **4425 kWh/m³ = 4,43 kWh/Liter**

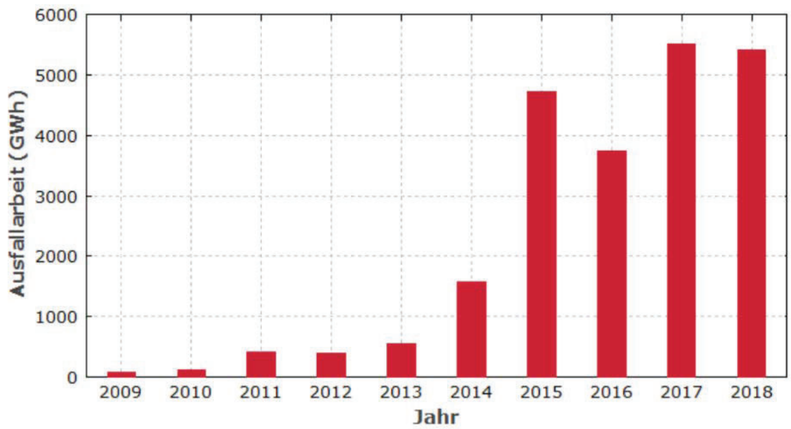
  Compare: Diesel, 835kg/m³ → 9740kWh/m³ = 9,74kWh/Liter

  ✓ Storage, Logistics, Infrastructure

Not the alternative with the highest efficiency will win, but the one which offers the best compromise. Mostly this will relate to overall cost, which covers for cheapest energy production, best handling and logistics. But also **availability, scalability to immense quantities and robust and cheap production** will be essential, as well as the **electricity generation in darkness, calm (no wind), and winter.** Also the **strategig reserve** of any nation, i.e. the energy storage for e.g. 6 months and last but not least **easy handling and comfort for the customer.**

„Waste wind energy“
also called „Ausfallarbeit“, „Überschussstrom“

- with the introduction of renewables, Wind and PV, there is more volatile energy in the European distribution network → production peaks can often not be used and must be compensated for with huge effort to maintain net stability
- → excess electricity could be used for electrolysis and PtX production
- **But how much excess energy is there?**
- **5,5TWh corresponds to only 0,15% of primary energy turn over**
- **reFuel production from „excess energy“ is by far insufficient, a dedicated energy strategy is needed!**



Source: Bundesnetzagentur und https://www.energie-lexikon.info/ausfallarbeit.html

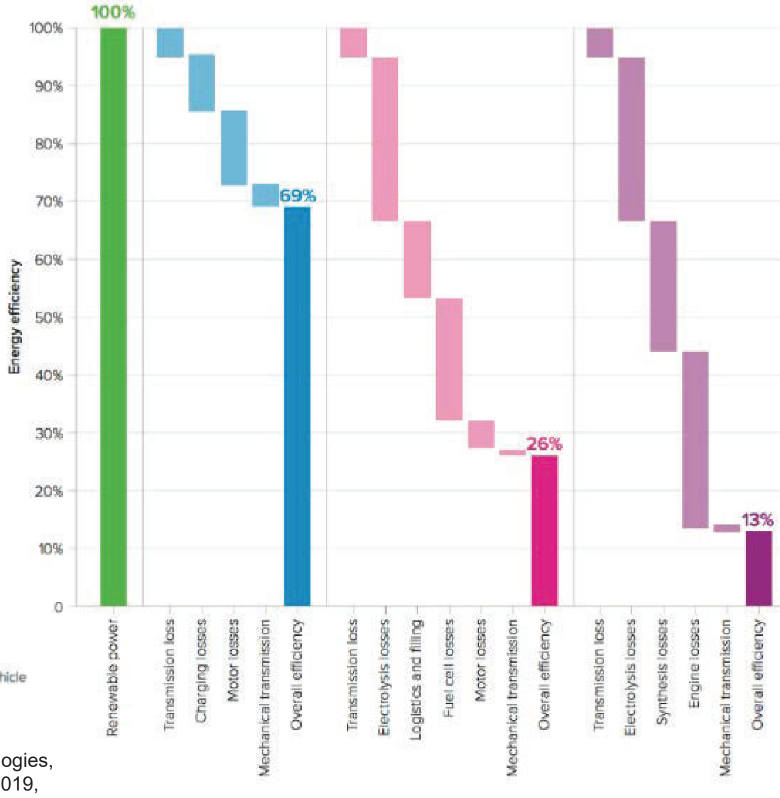
Efficiency of the production and use of regenerative fuels
Comparison to driving with electricity directly

Assumption: 100% energy (green column) is used to:

- drive a battery electric vehicle (blue)
- to run a fuel cell vehicle with hydrogen
- to run a Diesel vehicle with synthetic Diesel

In all of these scenarii the production of the vehicle and in particular the CO_2 intensive production of the battery is not included, nor is the infrastuctur to produce the necessary amount of green energy !

Glossary:
Transmission loss → losses in the electric Grid
Motor losses → losses in the electric motor, efficiency of the eMotor
Logistics and filling → storage, transport of H_2, both liquid and gaseous, consume energy. The filling process (of tanks), i.e. the transfer of H_2 from one vessel to another requires energy and incurs loss of H_2 (leakage, boiling losses, ….)
Synthesis losses: are a matter of debate and depend very much on the synthesised fuel. E.g. H_2+CO_2 → Methanol is an exothermic reaction, CO_2 can be captured „out of the air“ (400ppm vol → very energy consuming!) or „from industrial combustion“ (85% vol!)



Renewable power | Battery Electric Vehicle | Fuel Cell Vehicle | Efuel Diesel Engine Vehicle

Quelle: Matthew Davidson, Centre for Sustainable and Circular Technologies, University of Bath, at the IMechE IC Engines, Birmingham, December 2019,

Efficiency of the production and use of regenerative fuels
Comparison to driving with electricity directly

Assumption: 100% energy (green column) is used to:

- drive a battery electric vehicle (blue)
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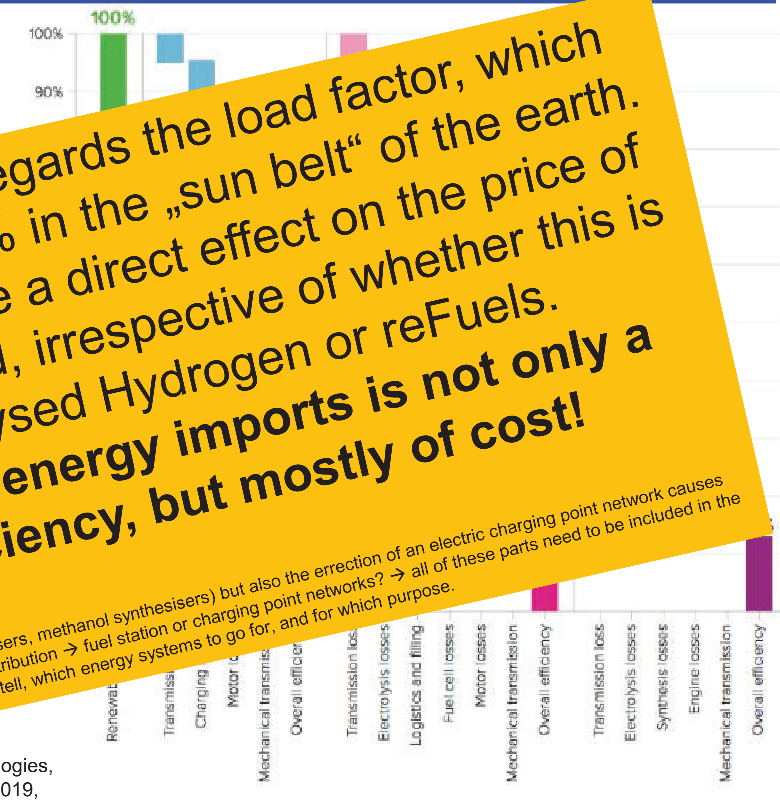
- to run a D



These consideration disregards the load factor, which may be as high as 60-70% in the „sun belt“ of the earth. This obviously does have a direct effect on the price of the unit energy produced, irrespective of whether this is electricity, electrolysed Hydrogen or reFuels.

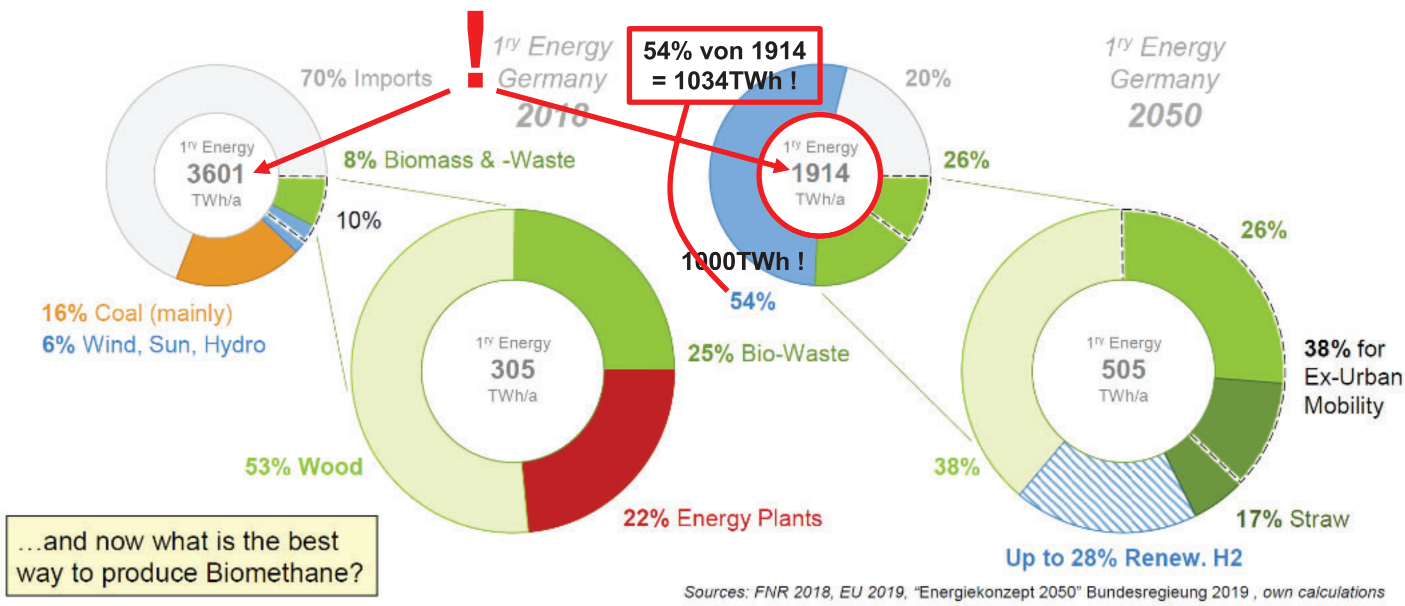
The solution for the energy imports is not only a question of efficiency, but mostly of cost!

Not only building wind turbines, PV or chemical plants (electrolysers, methanol synthesisers) but also the errection of an electric charging point network causes huge investments, as well as that for energy production and distribution → fuel station or charging point networks? → all of these parts need to be included in the Life Cycle Assesment LCA of cost and efficiency. Only this will tell, which energy systems to go for, and for which purpose.

Quelle: Matthe ...ainable and Circular Technologies, University of B ...E IC Engines, Birmingham, December 2019,

Forecast, Energy supply in 2050

Sources: Sens, Brauer et al, IAV, in SAE ICE 9/2019 und FNR e.V., own calculations



→ Biomass used for Sustainable Mobility shall not compete with the Food Supply!

Is the plan/the forecst for 2050 realistic at only 1914 TWh ?
A linear extrapolation of the reduction from 1990 bis 2020 indicates app. 3000 TWh !

FNR Fachagentur Nachwachsende Rohstoffe e.V.

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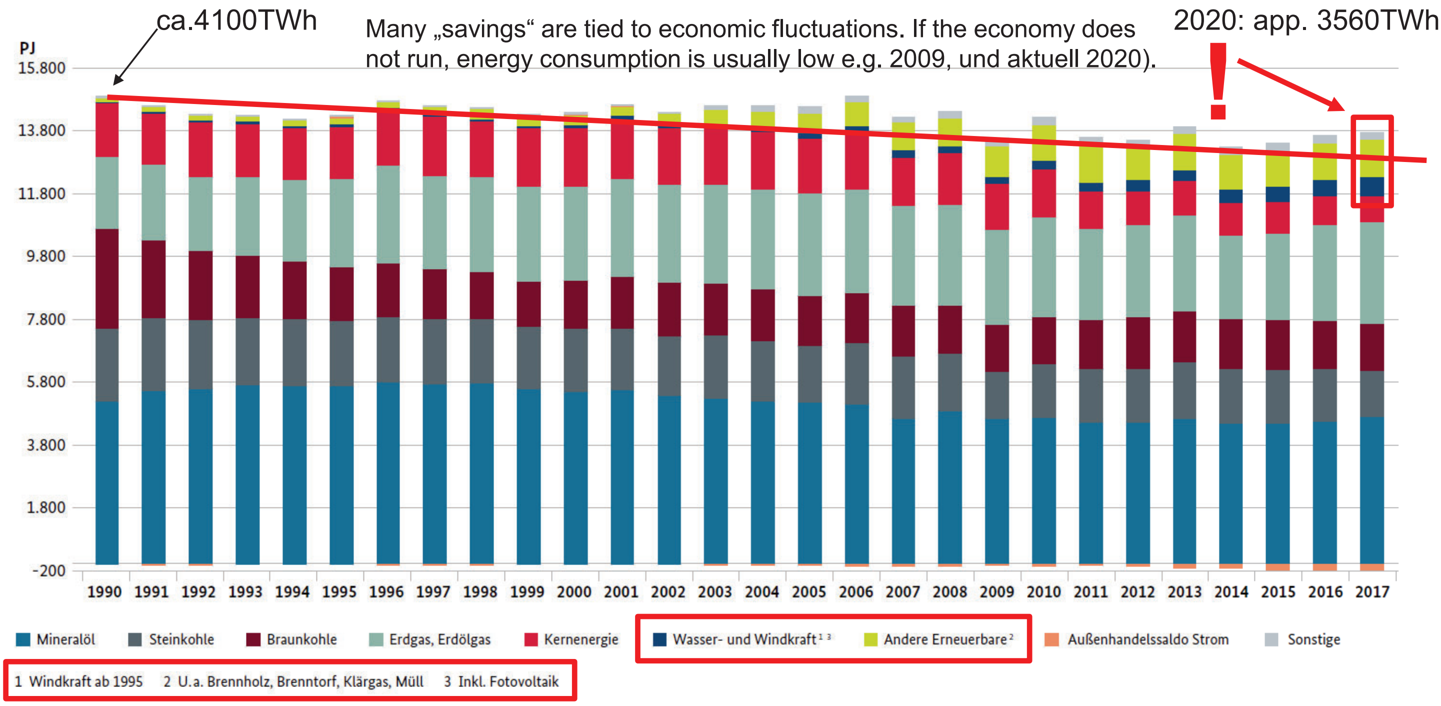
Primäry Energy Consumption in Germany from 1990 - 2017



Quelle: Arbeitsgemeinschaft Energiebilanzen (AGEB)

(optimistic) **Linear Forecast for 2050: app. 3000 TWh**

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Conclusions (short version)

- **Industrialised countries are likely to depend on energy imports**, when the available land surface and the yield from wind and PV is limited.
- **For this import only energy carriers are suitable with simple, scaleable, robust and cheap production, reasonable volumetric energy density and simple handling .**
- **Green electricity resp. Hydrogen as base substance will be needed in vast quantities → there is by far enough energy from the sun belt of the earth**
- for **mobile applications** and **long distance energy logistics** **liquid fuels** have essential advantages in energy density, handling and range vs. gaseous fuels.
- splitting liquid fuels back into hydrogen does not make any sens. Combustion engines can use these fuels directly and energy storage also is soved with liquid fuels.
- Nowadays the cleansing of combustion engine emissions is a solved issue.

Conclusions (long version)
We will need ALL technologies, battery-electric, Hydrogen, eFuels !

- Germany or any other industrialised country with limited geographical and geological resources will always remain dependent on **imports**. Nevertheless the **share of renewable energies** must be increased vastly from currently **less than 20% of the total energy turnover**. This includes all forms of energy, not only electric (mechanical, heat).
- Subsequently this is only possible in a **globalised energy economy**, where the transfer of energy will only be possible in few cases by cable (electricity) or pipeline (Hydrogen, natural gas).
- The **transport of Hydrogen** in pipelines will be favourable for some application e.g. a national grid. However, for long distance transport its **volumetric energy density is unfavourably low, supercooling and compression energetically not sensible**.
- A **liquid energy carrier** with **reasonable volumetric energy density**, which can be produced with **reasonable efficiency, robustly, simple and scaleable to huge quantities** is Methanol. (Source: e.g. Prof. Bertau (Bergakademie Freiberg) et.al. Methanol: The basic Chemical and Energy Feedstock of the Future, Springer Verlag; Prof. Robert Schlögl, Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin). **Methanol** is liquid at ambient pressure and temperature, i.e. handling is simple. It can be used in fuel cells and combustion engines. Toxicity appears to be one topic of discussion, however, gasoline is not less toxic and intoxications are rather rare! Methanol can be processed to eKerosene and eDiesel, as well as eGasoline to serve to **defossilise the existing vehicle fleet**. Also other renewable fuels, e.g. from waste, appear attractive from their energetic balance as well as cost → Prof. Willner, HAW Hamburg
- Closed Carbon Cycle→ H_2 electrolysed from green electricity and synthesised with recycled carbon(dioxide) to new fuel.
- **direct air capture of CO_2** → currently still **complex and expensive,** because the **concentration in air is only 0.04%.**
- **Recycling from so called point sources (= industrial plants) is much less complex and cheaper (app. factor of 4).** For a long time to come there will be a **sufficient number of point sources** (waste incineration, concrete works, others) **to satisfy the Methanol/energy demand of the world.** **The CO_2 concentration in such exhaust gases is some 5 – 15%** (depending on process and operation condition). The fuel produced from recycled carbon will then be CO_2 neutral, not CO_2 free . **Nevertheless, the carbon footprint will still be vastly reduced.**

Sensible market division:

- **short distance and low power density** applications → **battery electric**
- **middle distance und medium power** (distributors, communal vehicles, bus fleets) → **hydrogen combustion engine** (technology quickly available, transient operation needs some develoment) and **fuel cell** (not in serial production yet)
- **long distance and high power demand**: long haul trucks, building and agricultural machinery (refuelling, operational hours per day), railways which cannot be electrified economically, aviation → combustion engines with **eFuels from various sources**

Questions, answers, and comments

Q. Whenever we have argument about this with people from other field, they talk about economic liability and efficiency. Can you mention quantitatively?

A. I have not researched overall efficiency in depth. However, according to a swiss magazine article, energy generation with stream turbine and coal fire plant, efficiency is 35-40% and combined efficiency is 80-85%. It is unfair comparison since the heat can be generated elsewhere and this is what Thomas argued. Increased electricity because of the battery car will be generated from the fossil fuel.

C. Electrical car is more energy efficient. However, from the hybridization, modern Truck efficiency is 40-42% and passenger car is 40%.

Q. If you would convert the strategic oil reserve in US to equivalent energy quantity of batteries, you need to spend 5000 years of global GDP.

A. Methanol as the basic substance, low burstiness, cheapness, and durability, but not efficiency. Under 1cent/kwh in Saudi Arabia PV

Japanese policy for carbon neutrality and e-fuel

Akiteru Maruta

Technova Inc.

About the speaker:

- Project Manager in Energy Research Department, Technova Inc., Tokyo, Japan
- PhD at University of Tokyo
- Project associations with NEDO, METI, and HyGrid Study Group in Japan

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ReFuel 2021　9 Sept, 2021

Japanese policy for carbon neutrality and e-fuel

Akiteru (Aki) MARUTA, Ph.D.
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Technova, Inc　　maruta@technova.co.jp

Contents

TECHNOVA

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The information, including translation, analysis and comments in this presentation are those of the author and do not necessarily reflect the official position and opinion of neither the Japanese Government nor any Japanese companies.

E-Fuel: Definition

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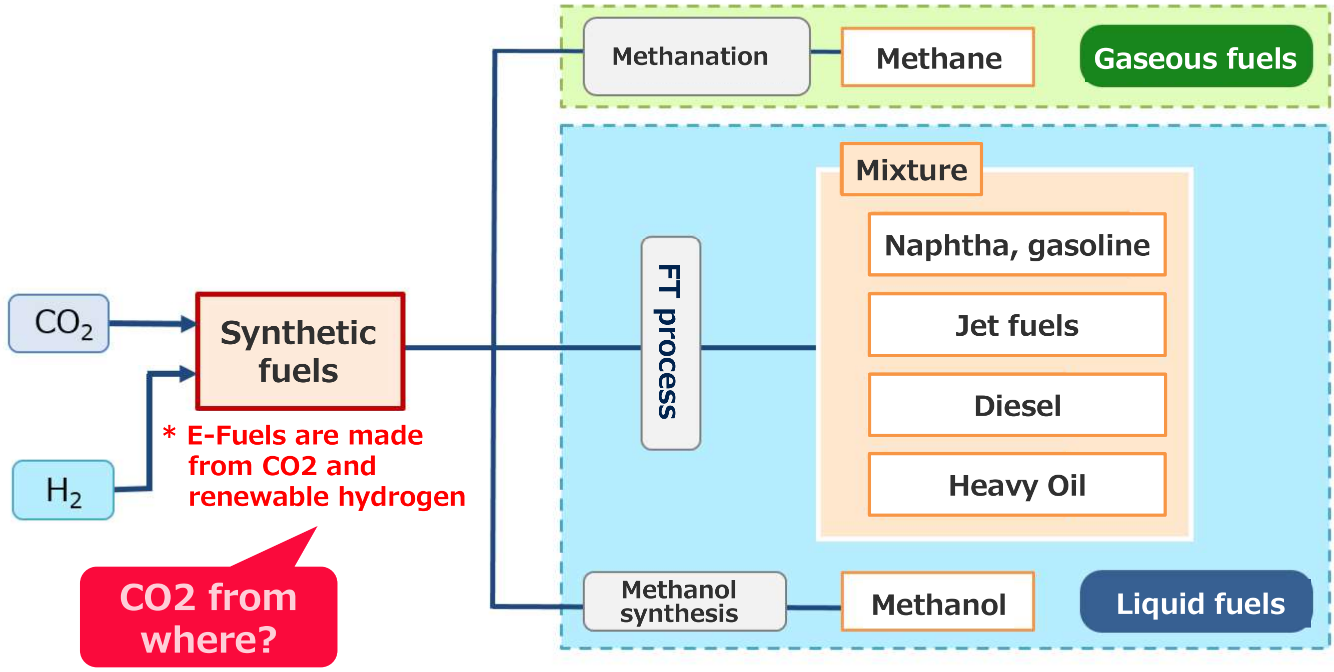
- E-Fuel requires renewable hydrogen (the definition?)



Source: METI “Green Synthetic liquid fuels” (featured contents)

Unofficial Translation

Policy: Zero Carbon by 2050 and Green Growth Strategy

Policy: Zero Carbon by 2050

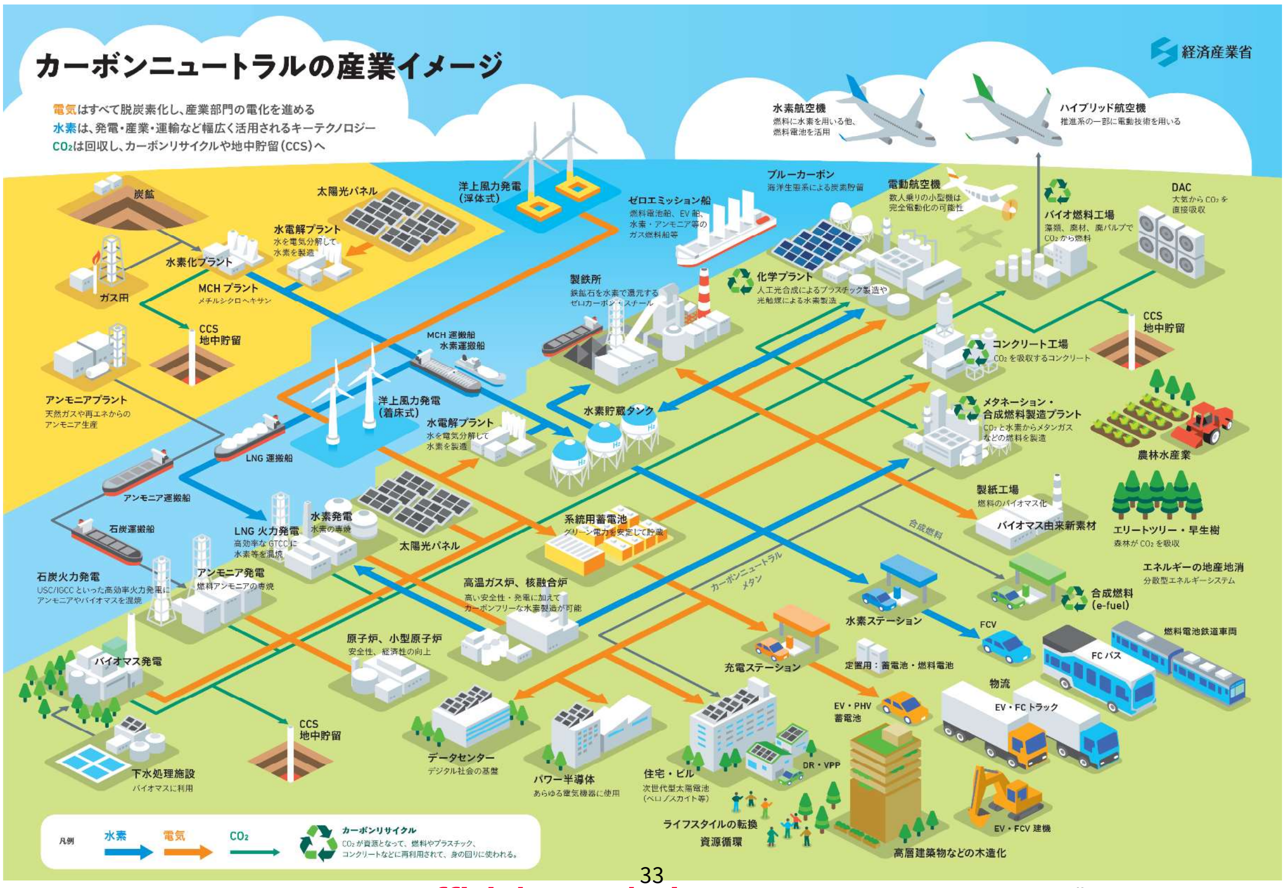
- **Green Growth Strategy is the key policy for net zero 2050**

(Policy Speech by the Prime Minister to the 203rd Session of the Diet, 26 Oct 2020)

"We hereby declare that **by 2050 Japan will aim to reduce greenhouse gas emissions to net-zero**, that is, to realize a carbon-neutral, decarbonized society"

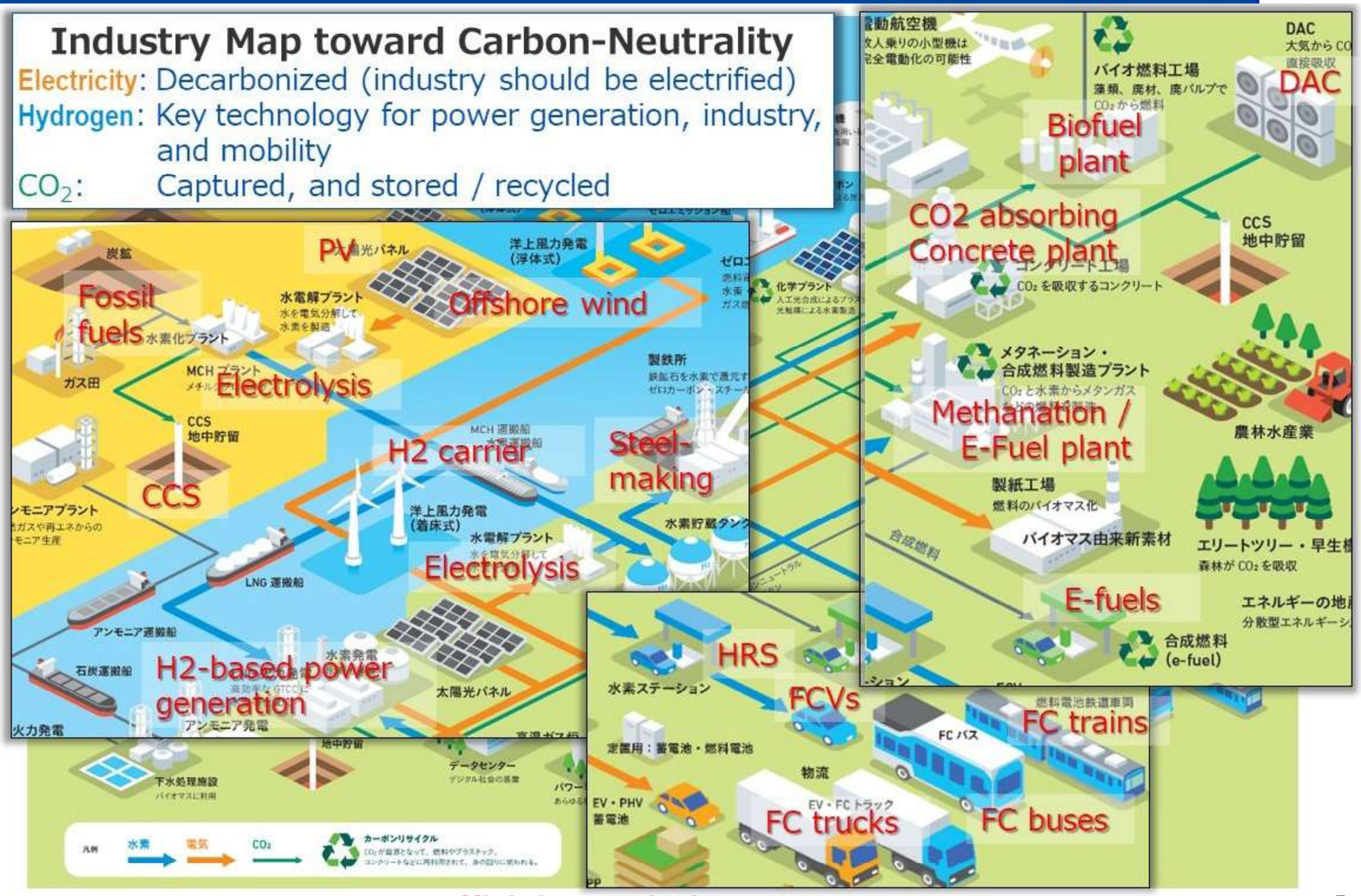
Green Growth Strategy (25 Dec 2020)
Updated **Green Growth Strategy** (18 June 2021)

Green Growth Strategy (issued in Dec 2020): Industry Map toward Carbon-Neutrality



Source: METI "Green Growth Strategy" **Unofficial Translation**

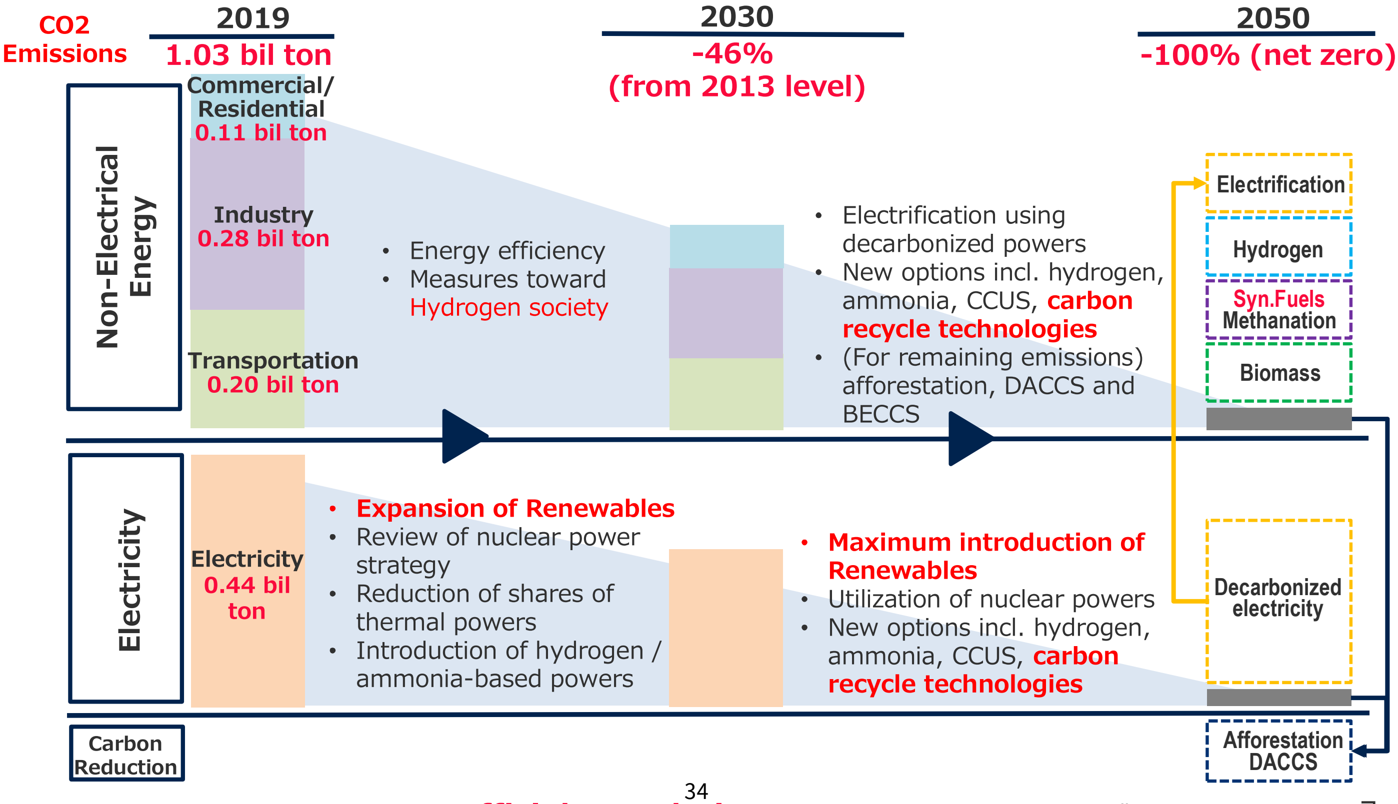
Green Growth Strategy (issued in Dec 2020): Industry Map toward Carbon-Neutrality



Source: METI "Green Growth Strategy" **Unofficial Translation**

Green Growth Strategy (June 2021): Main Concept Toward Net Zero 2050

- **Mix of measures are needed for Net Zero 2050**



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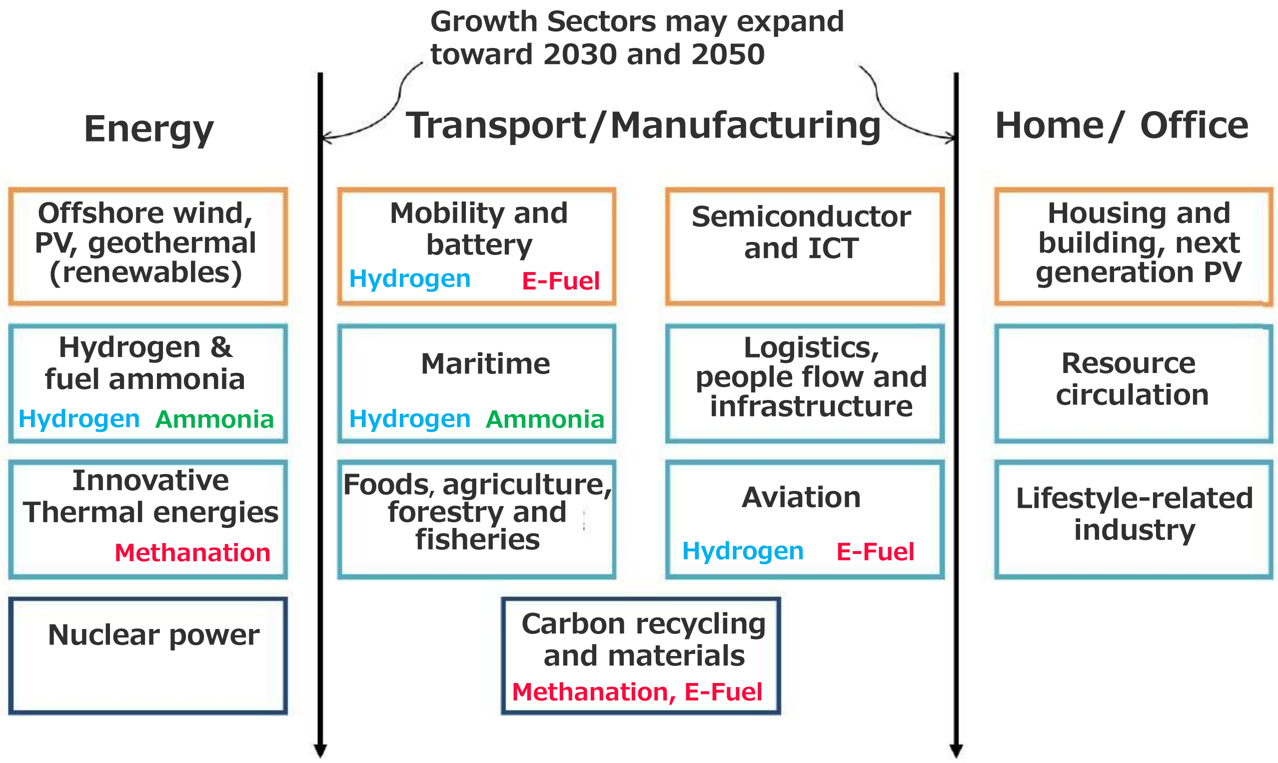
Source: METI "Green Growth Strategy" **Unofficial Translation**

Green Growth Strategy (June 2021): 14 Growth Sectors

TECHNOVA

- Hydrogen and E-Fuel are key for de-carbonization of Sectors



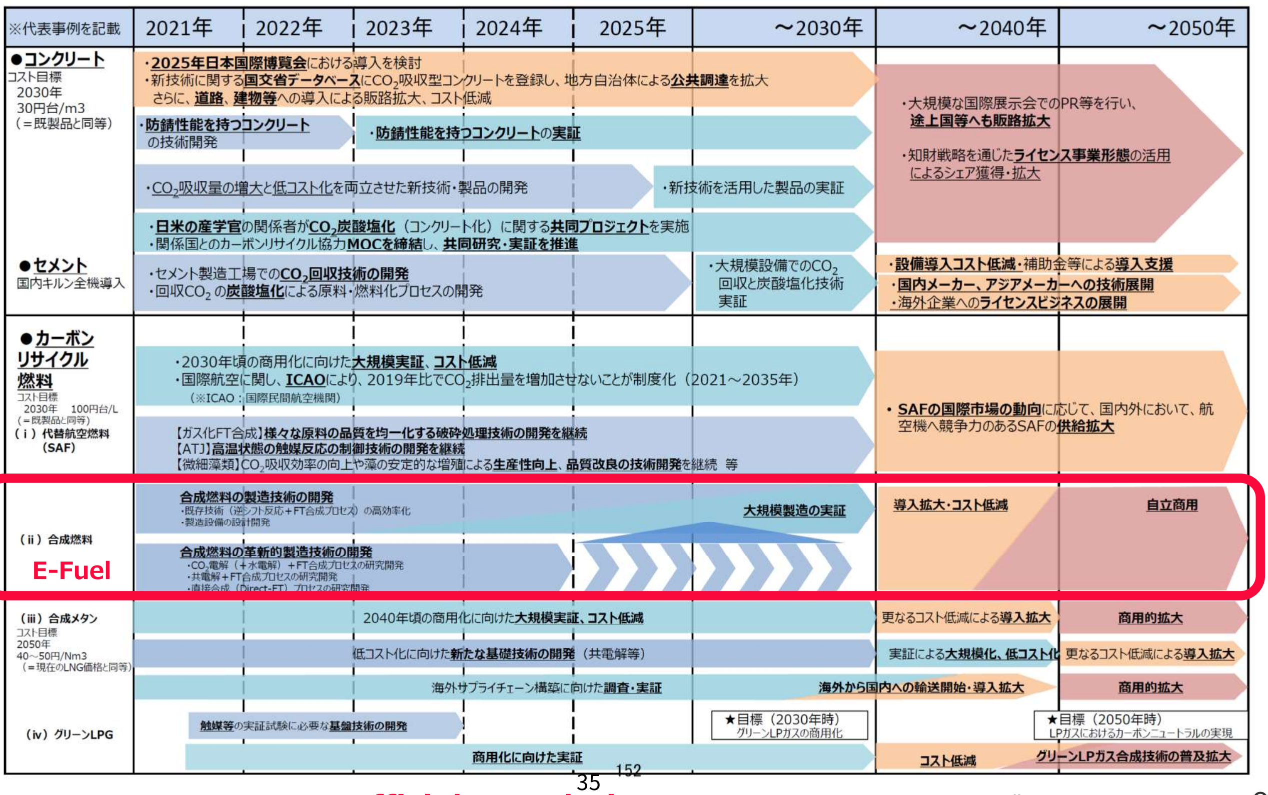
Green Growth Strategy (June 2021): Roadmap on Carbon Recycling and Materials

TECHNOVA

Roadmap on Carbon Recycling and Materials

●導入フェーズ： 1．開発フェーズ 2．実証フェーズ 3．導入拡大・コスト低減フェーズ 4．自立商用フェーズ

●具体化すべき政策手法： ①目標、②法制度（規制改革等）、③標準、④税、⑤予算、⑥金融、⑦公共調達等



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Green Growth Strategy (June 2021): Roadmap on Carbon Recycling and Materials

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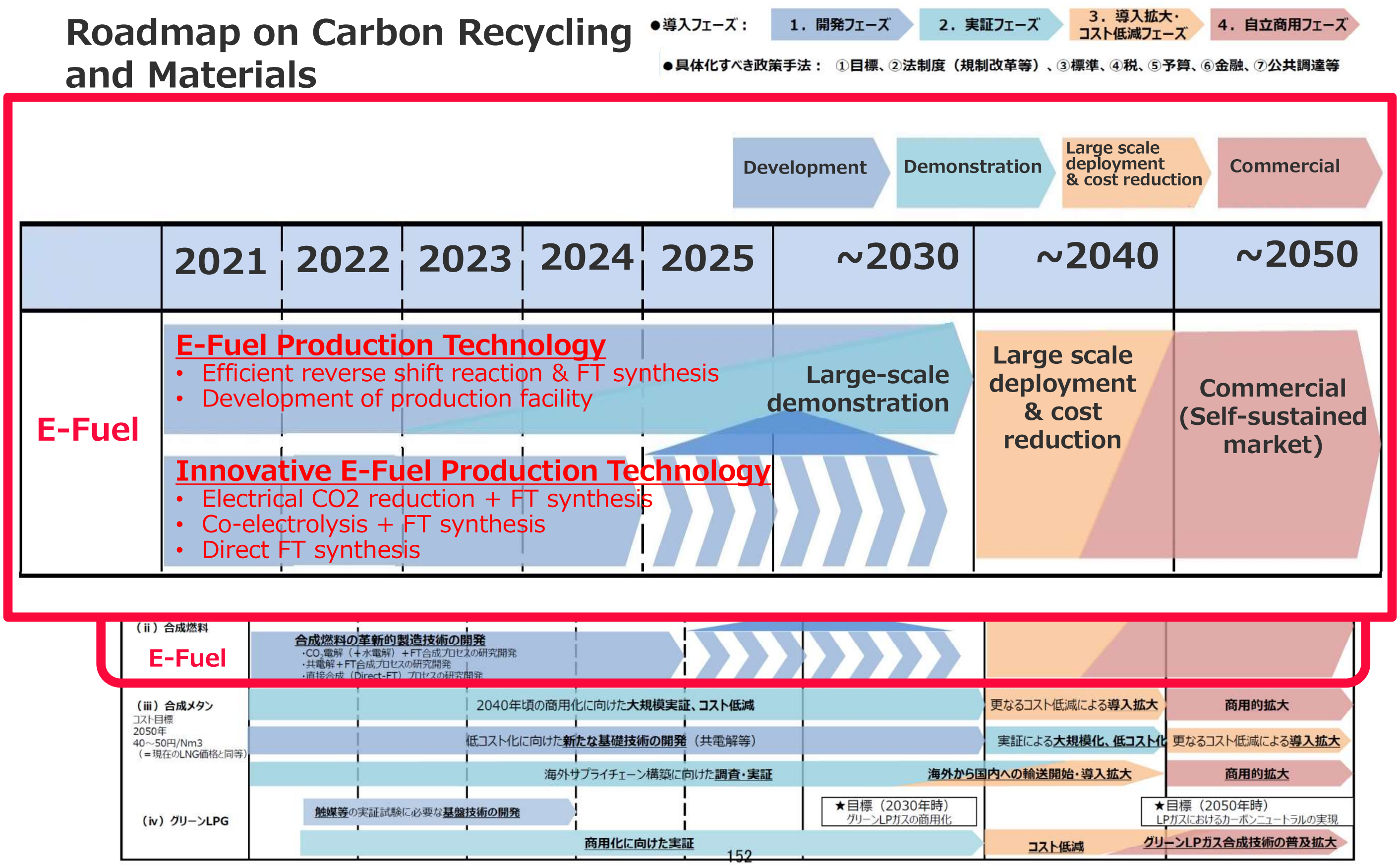
Roadmap on Carbon Recycling and Materials



Source: METI "Green Growth Strategy" **Unofficial Translation**

Green Innovation Fund (2021-2030)

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- **2 trillion yen (15 billion EUR) for 10 years, managed by NEDO**

* Call for proposals (CfP)
** Announcement of adopted projects

Priorities

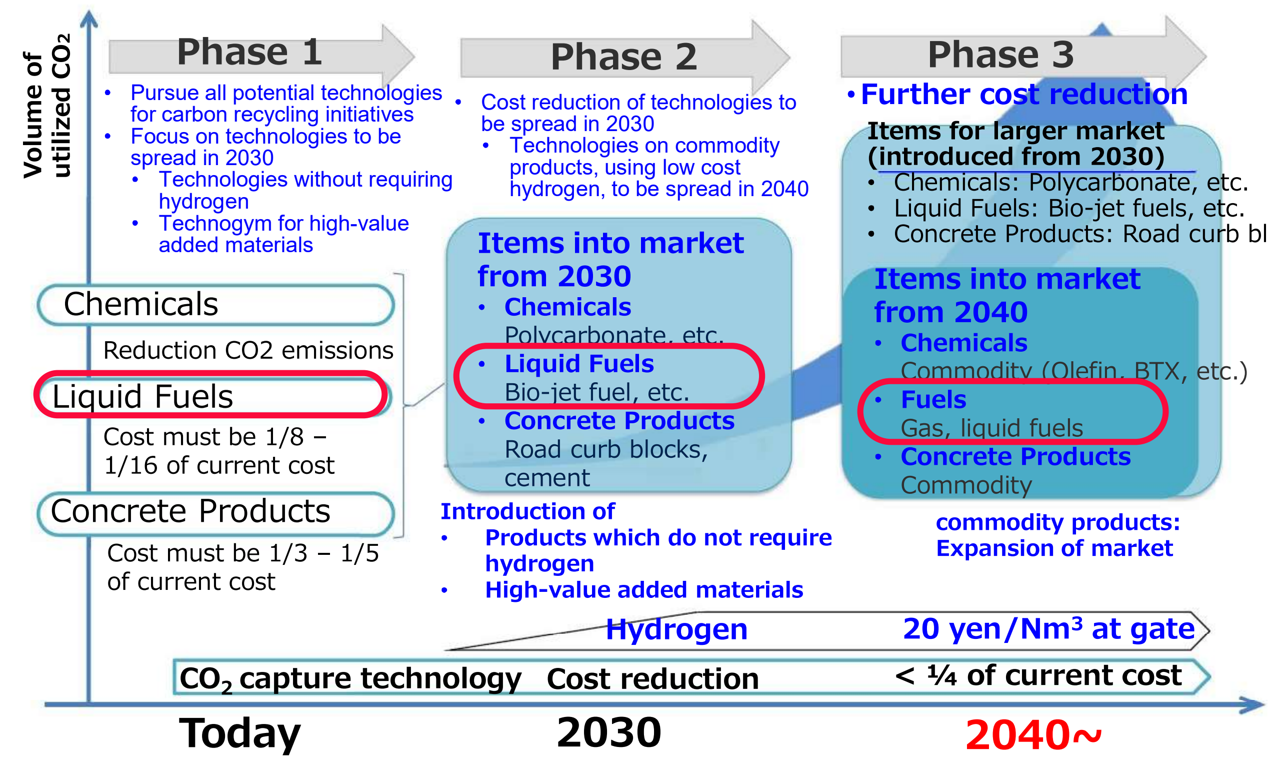
1. Off-shore wind
2. Next-generation PV
3. Large-scale hydrogen supply-chain **
4. Electrolysis for green hydrogen **
5. Hydrogen steel-making
6. Fuel ammonia supply-chain
7. CO2 recycling for plastic materials
8. **CO2 recycling for fuels (auto, aviation, residential/commercial)** **< CfP is planned >**
9. CO2 recycling for concrete products
10. CCUS
11. CO2 capturing technology at incinerators
12. Next generation batteries and motors
13. Innovative supply-chain for automotive electrification
14. Smart Mobility Society
15. Next generation digital infrastructure
16. Next generation aircrafts *
17. Next generation ships *
18. CO2 reduction / storage in Foods, agriculture, forestry and fisheries

Source: METI "Green Innovation Fund" **Unofficial Translation**

Policy: Carbon Recycling Roadmap

Roadmap for Carbon Recycling Technologies (originally in June 2019, updated in July 2021)

- **E-Fuel: Starting from SAF, then to road fuel (E-Fuel)?**



Source: METI "Roadmap for Carbon Recycling Technologies"

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Unofficial Translation

NEDO: R&D of liquid fuel Production Technology from CO2

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- **NEDO adopted FT synthesis Fuel project (from NEDO news release)**

Project: P&D on carbon recyle liquid fuel using CO2 (Feb 22, 2021)
https://www.nedo.go.jp/news/press/AA5_101410.html

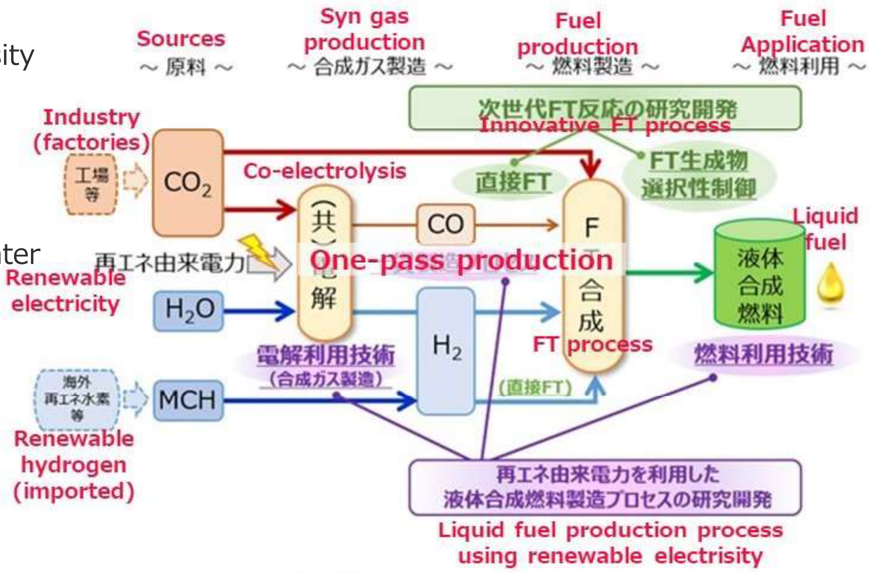
Unofficial Translation

Topics
- R&D on innovative FT synthesis
- P&D on synthetic liquid fuel production process using renewable electricity

Project Team
- Seikei Gakuen Seikei University
- ENEOS Corporation
- Nagoya University
- Yokohama National Univ
- Idemitsu Kosan Co., Ltd.
- AIST
- Japan Petroleum Energy Center

Project Term
- FY 2021-FY 2024

NEDO Budget
- 4.5 bil yen (34 mil EUR)



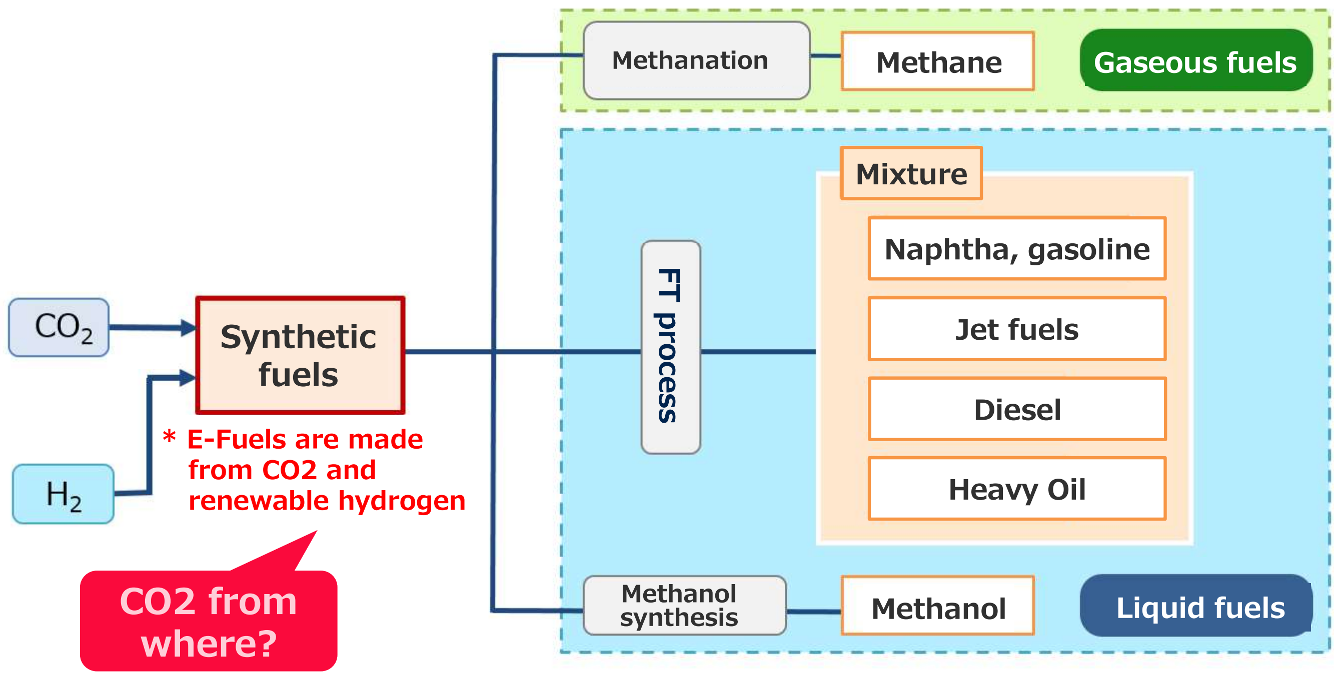
Source: NEDO News on Feb 22, 2021 **Unofficial Translation**

Toward Carbon-Neutral E-Fuel

Disclaimer
The information, including translation, analysis and comments in this presentation are those of the author and do not necessarily reflect the official position and opinion of neither the Japanese Government nor any Japanese companies.

What is the Carbon-neutrality of E-Fuel?

- **E-Fuel: Hydrogen – Clear, CO2 – Where?**

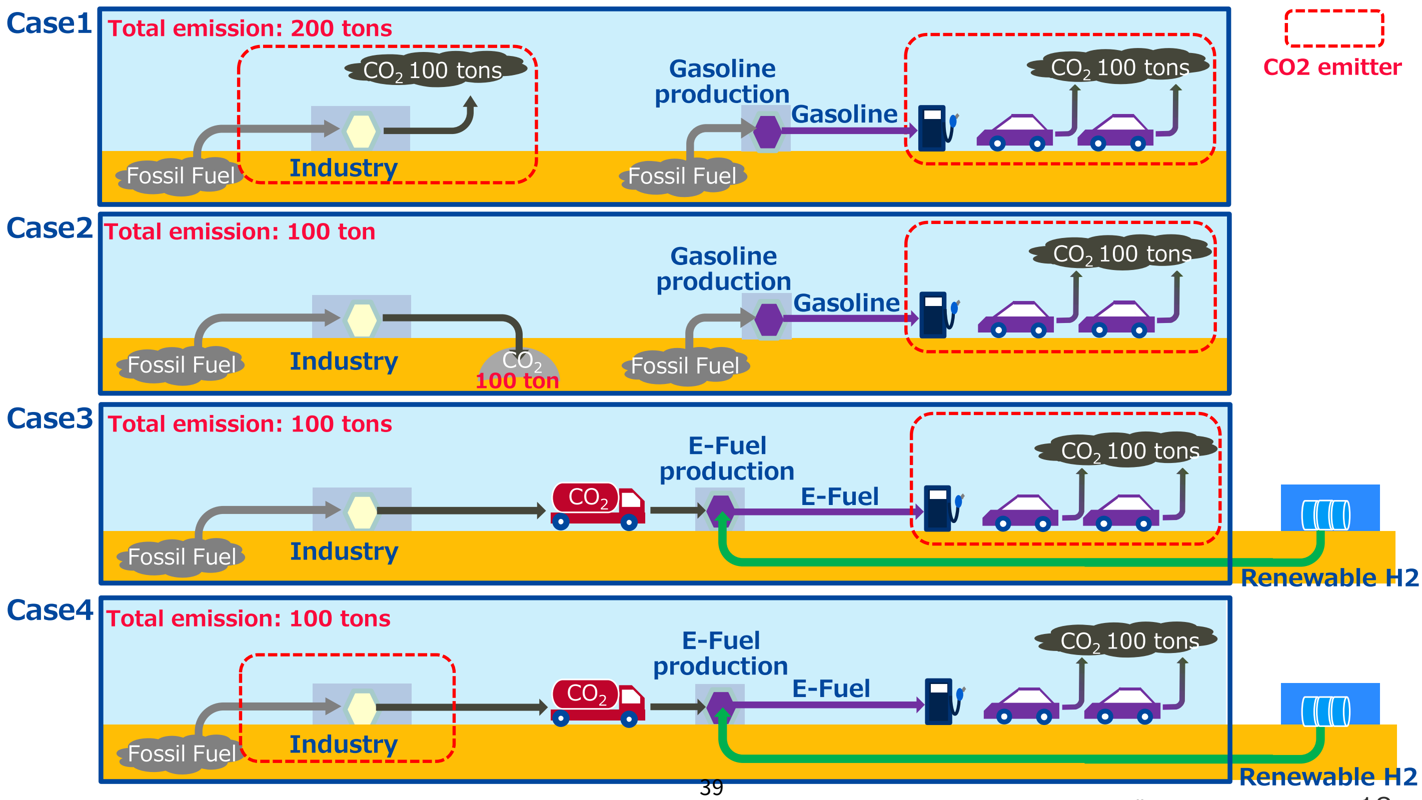


Source: METI "Green Synthetic liquid fuels" (featured contents)

Unofficial Translation

Carbon-neutrality of E-Fuel (1)

- **With industry-based CO2, E-fuel is not carbon-neutral**



Carbon-neutrality of E-Fuel (1)

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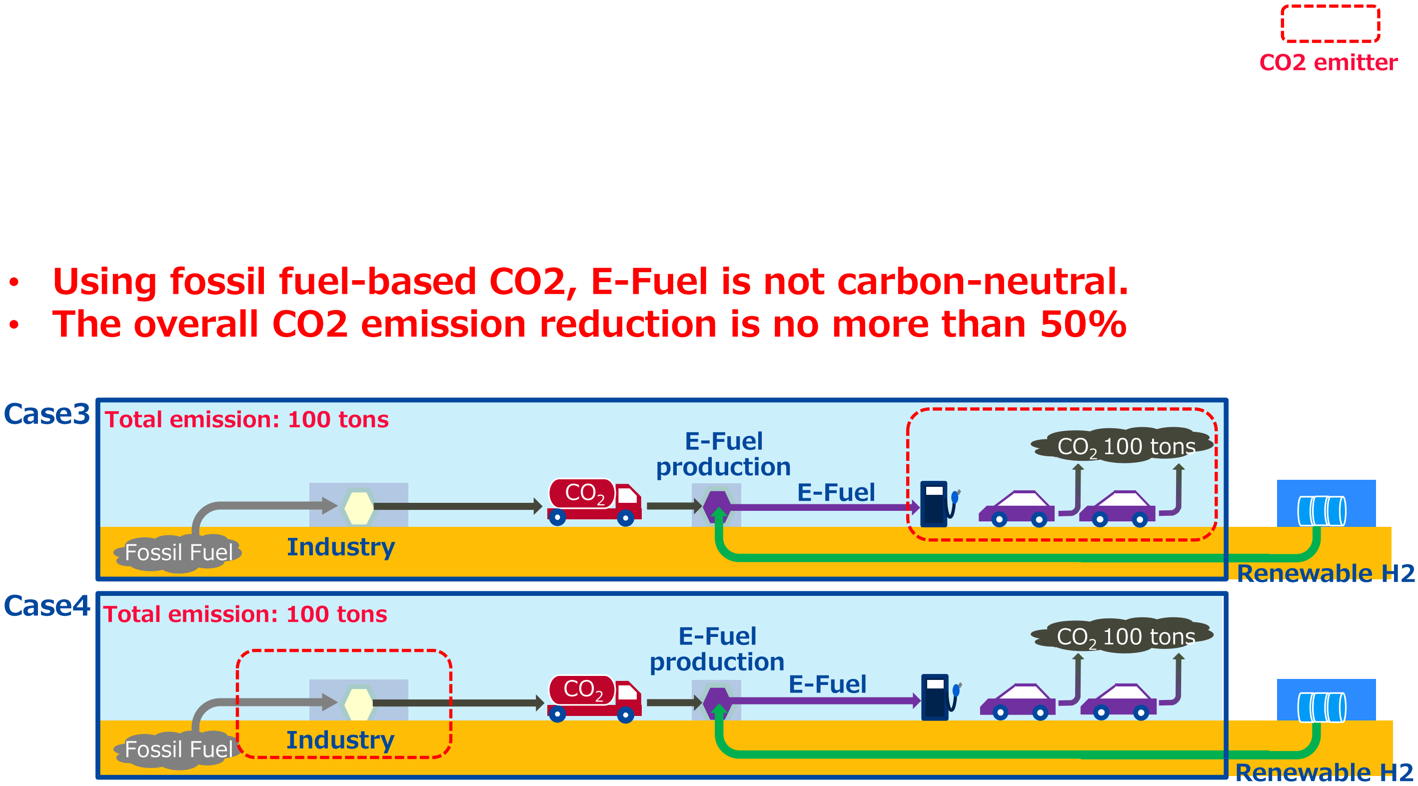
- With industry-based CO2, E-fuel is not carbon-neutral

- Using fossil fuel-based CO2, E-Fuel is not carbon-neutral.
- The overall CO2 emission reduction is no more than 50%



Carbon-neutrality of E-Fuel (1)

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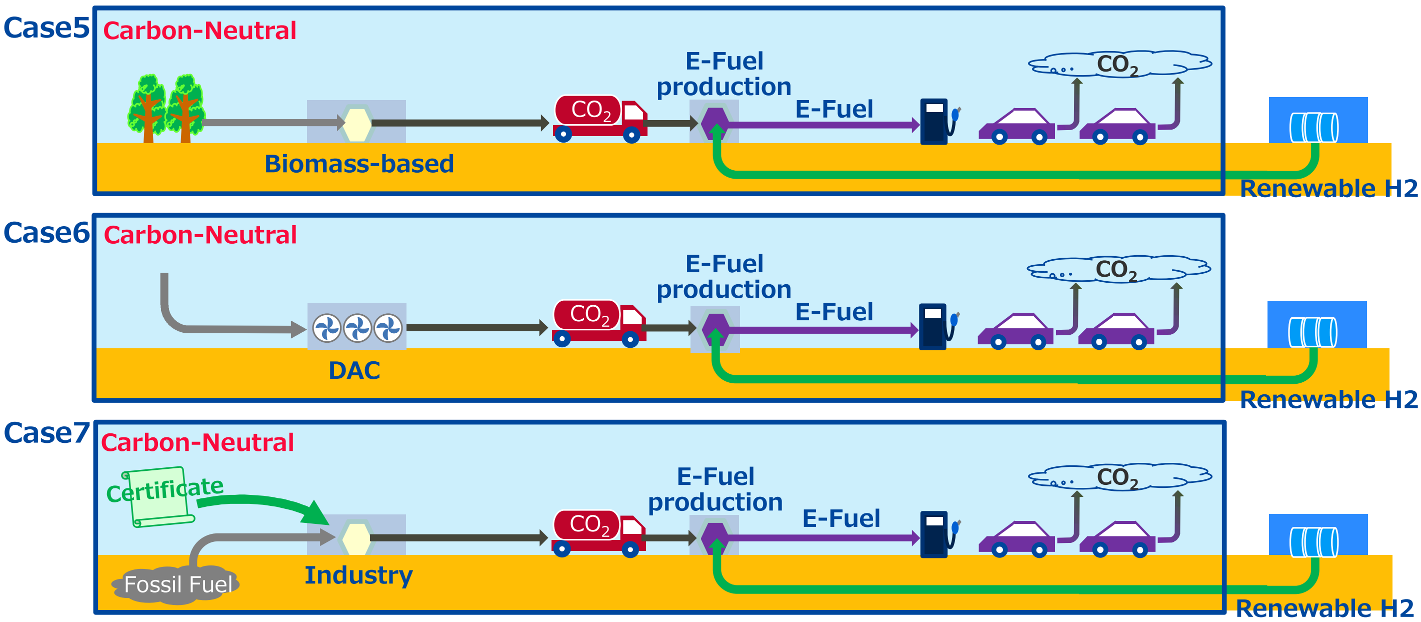
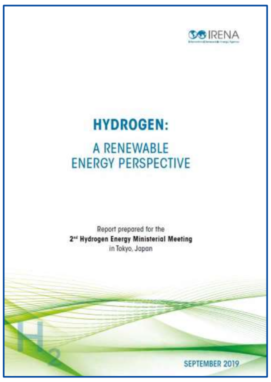
- To make E-Fuel carbon-neutral, there are seral ways…



- For carbon-neutral E-Fuel, DAC is an option.

Carbon Source: DAC

- DAC offers significant potential for E−fuel



IRENA
"Hydrogen:
A renewable energy perspective"
(Sept 2019)

Direct air capture of CO_2

Because a primary driver for the energy transition is abatement of greenhouse gas emissions, the source of the CO_2 used for producing e-fuel is important. **If the CO_2 is captured from a fossil fuel combustion** process (e.g., a power plant) and is reacted with renewable hydrogen to yield an e-fuel, and **this e-fuel is used to replace fossil fuel (e.g., jet fuel), then the total CO_2 emissions of both processes are halved.** However, this is **not in line with the Paris climate objectives**, which require significant de-carbonisation of the global economy in the second half of this century.

This leaves as **options only CO_2 from biomass combustion and from direct air capture (DAC)**. The first option is less costly yet limited in potential (*e.g.*, biomass combustion is only possible in large power plants, biofuel refineries, bagasse boilers and pulp plants). **The second (DAC) is costlier but has unlimited potential**, provided that significant cost reductions take place and that the price for CO_2 is sufficient to support investments in such technologies.

Conclusion

Conclusion

- **Policy: Zero Carbon by 2050 and Green Growth**
  Policy: Carbon Recycle
  - Under Green Innovation Growth Initiative, Government promotes hydrogen, ammonia and E-Fuels.
  - E-Fuel can contribute to industry growth as well as decarbonization.
  - E-Fuel may be introduced into the market around 2040.
  - E-Fuel may start from SAF, and then to road fuel.

- **Toward Carbon-Neutral E-Fuel**
  - If fossil-fuel based CO2 for E-Fuel, “someone” must be responsible for CO2 emission (and CO2 emission reduction is no more than 50%)
  - To guarantee carbon neutrality for E-Fuels, DAC technology is the key.
  - Carbon neutral E-Fuels can compete with other carbon-neutral technologies (electricity, green/blue hydrogen and others).

Questions, answers, and comments

Q. All of the activities you mentioned need a lot of investment and legal agreement. Do you seem such a plan you proposed by the committee that implement the conditions and investment find business potential?

A. We need international discussion, which we are going to do. We have to understand global big picture. Our government will support the vision, as long as it supports the decarbonization.

ReFuel 2021

E-fuel contribution via R&D in Finland

Martti Larmi

Aalto University

About the speaker:

- Professor in Energy Technology and Head of Energy Conversion Research Group at Aalto University
- PhD at Helsinki University of Technology
- Professional career at Wärtsilä

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E-fuel contribution via research and development in Finland

Martti Larmi & Michal Wojcieszyk & Annukka Santasalo-Aarnio & Ossi Kaario & Qiang Cheng & Ville Vuorinen

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Professor, Aalto University
9th September 2021

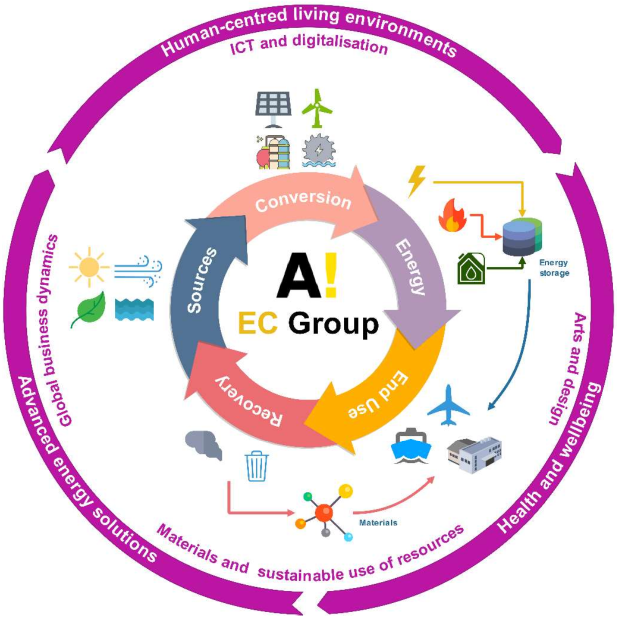
Research Group of Energy Conversion

Aalto University
School of Engineering

Head
Prof. Martti Larmi

Prof. Ville Vuorinen

Aalto University



https://youtu.be/mK41f24lX1k

Prof. Annukka Santasalo-Aarnio

Prof. Mika Järvinen

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Agenda

1. **Overview of e-fuels**
2. **Current e-fuel projects in Finland**
3. **Aalto University activities in the field of e-fuels**

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Agenda

1. **Overview of e-fuels**
2. Current e-fuel projects in Finland
3. Aalto University activities in the field of e-fuels

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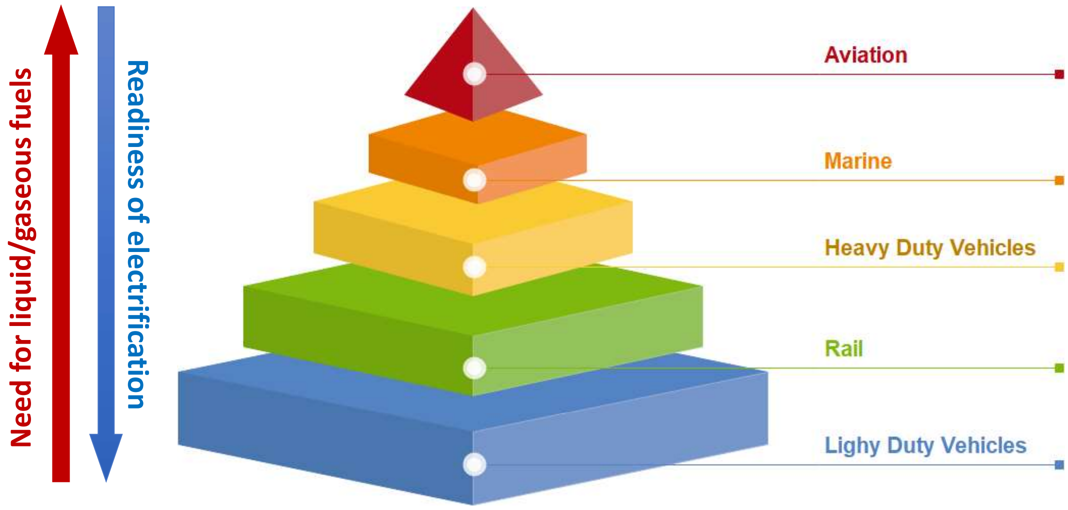
In decarbonization of transport...

...each segment needs tailored solutions



0.1%

current use of low carbon fuels in shipping*

* IEA (2020), *International Shipping*, IEA, Paris https://www.iea.org/reports/international-shipping

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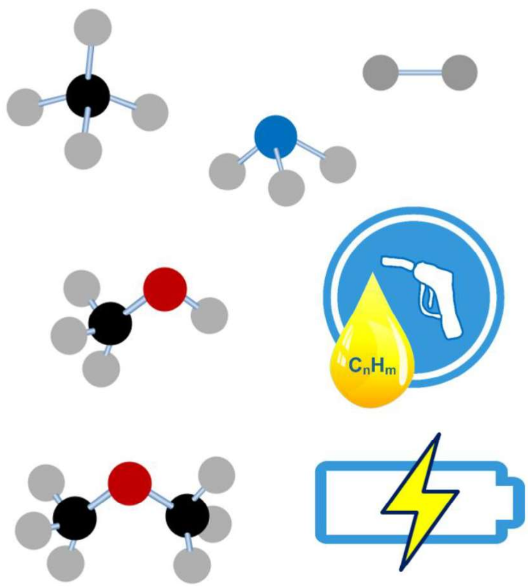
E-fuels as energy carriers for hard-to-abate sectors

Promising examples:

- Methane
- Methanol
- Ammonia
- Hydrogen
- FT fuels
- Dimethyl ether



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Hydrogen

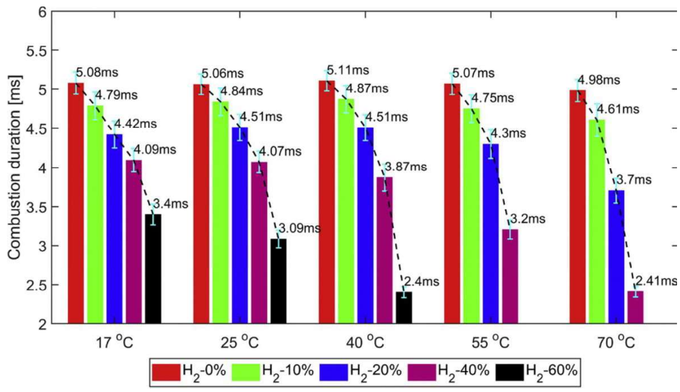
H_2

Benefits:

- Carbon-free e-fuel when integrated with renewable electricity
- Can be used either in ICE (addition to LNG, Otto or Diesel concept) or in fuel cells

Challenges:

- Infrastructure
- Storage and volumetric energy density
- Difficult to control combustion (very high flame speed)
- Hydrogen embrittlement
- Injection system



1. Figure: Cheng, Q., Ahmad, Z., Kaario, O., Vuorinen, V. and Larmi, M., 2021. Experimental study on tri-fuel combustion using premixed methane-hydrogen mixtures ignited by a diesel pilot. *International Journal of Hydrogen Energy*.
2. Verhelst, S. and Wallner, T., 2009. Hydrogen-fueled internal combustion engines. Progress in energy and combustion science, 35(6), pp.490-527.

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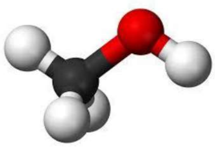
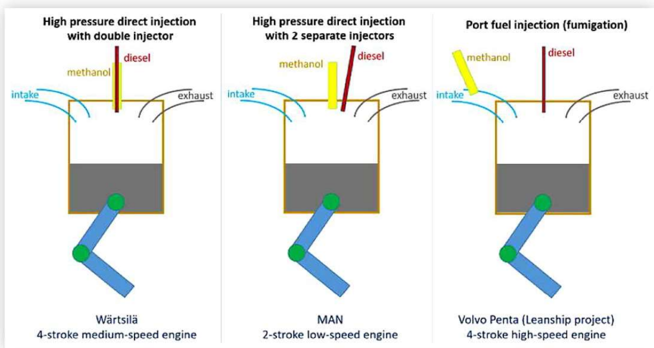
Methanol

CH_3OH



- Storage in atmospheric conditions (liquid)
- Biodegradable and miscible with water, far less toxic for aquatic life than HFO/MDO
- Need for dedicated engines or retrofitting
- Successfully demonstrated combustion concepts[1]
- Significant decrease in local emissions (no SO_x and PM, lower NO_x)

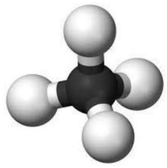
FIGURE 10 Three methanol dual-fuel engine concepts successfully demonstrated in the marine market.



1. Figure: Santasalo-Aarnio, A., Nyari, J., Wojcieszyk, M., Kaario, O., Kroyan, Y., Magdeldin, M., Larmi, M. and Järvinen, M., 2020. *Application of Synthetic Renewable Methanol to Power the Future Propulsion* (No. 2020-01-2151). SAE Technical Paper.
2. Verhelst, S., Turner, J.W., Sileghem, L. and Vancoillie, J., 2019. Methanol as a fuel for internal combustion engines. *Progress in Energy and Combustion Science*, *70*, pp.43-88.
3. Dong, Y., Kaario, O., Hassan, G., Ranta, O., Larmi, M. and Johansson, B., 2020. High-pressure direct injection of methanol and pilot diesel: A non-premixed dual-fuel engine concept. *Fuel*, 277, p.117932.

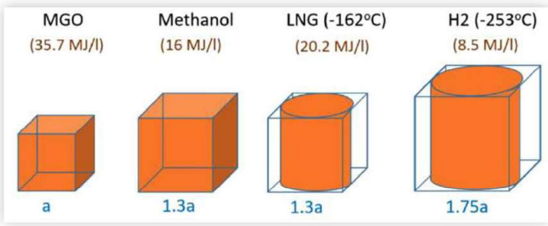
Liquified e-methane

CH$_4$



- Growing infrastructure for LNG compatible with LBG and liquified e-methane
- Commercial technology with available gas engines (dual-fuel, spark-gas)
- Emissions: no SO_x and PM, lower NO_x
- Methane slip issue (high GWP)

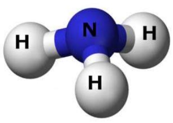
FIGURE 9 Required fuel tank space for the same autonomy of the vessel in case of fossil diesel oil, methanol, LNG, and liquid hydrogen. Example of a cubic shape tank, where 'a' is an arbitrary unit of the cube's dimension, and for LNG and H_2 cylindrical tanks required plus additional insulation.



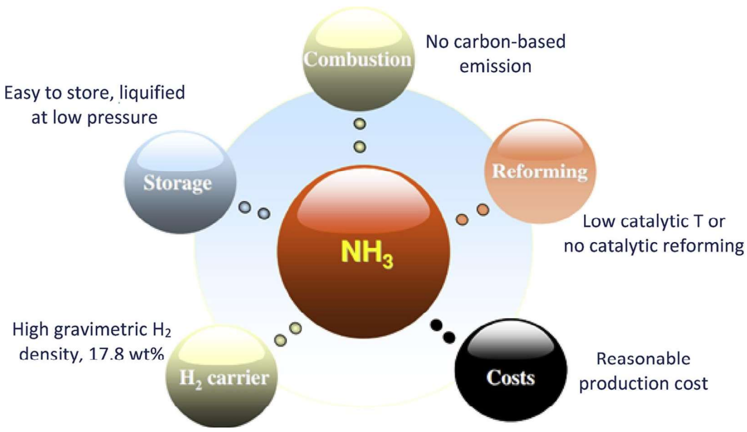
1. Figure: Santasalo-Aarnio, A., Nyari, J., Wojcieszyk, M., Kaario, O., Kroyan, Y., Magdeldin, M., Larmi, M. and Järvinen, M., 2020. *Application of Synthetic Renewable Methanol to Power the Future Propulsion* (No. 2020-01-2151). SAE Technical Paper.
2. Ahmad, Z., Kaario, O., Qiang, C., Vuorinen, V. and Larmi, M., 2019. A parametric investigation of diesel/methane dual-fuel combustion progression/stages in a heavy-duty optical engine. *Applied Energy*, 251, p.113191.

Ammonia

NH$_3$



Benefits:



Challenges:

- Low vol. energy density
- Low viscosity
- Corrosive
- High autoignition temp.
- Low flame speed
- Toxicity & emissions

Possibilities:

- Dual fuel combustion
- Hydrogen addition
- Other combustion concepts

1. Figure: Dimitriou, P. and Javaid, R., 2020. A review of ammonia as a compression ignition engine fuel. *International Journal of Hydrogen Energy*, *45*(11), pp.7098-7118.
2. Klüssmann, J., Ekknud, L. , Ivarsson, A., Schramm, J., Ammonia Application in IC Engines., IEA Advanced Motor Fuels Technology Collaboration Programme, May 2020.
3. Al-Aboosi, F.Y., El-Halwagi, M.M., Moore, M. and Nielsen, R.B., 2021. Renewable ammonia as an alternative fuel for the shipping industry. *Current Opinion in Chemical Engineering*, 31, p.100670.

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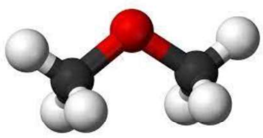
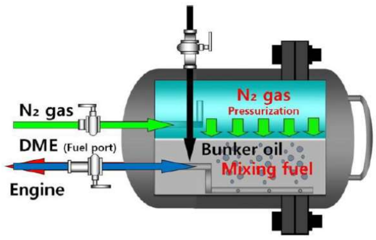
Dimethyl ether

CH_3-O-CH_3



Benefits:

- High cetane number
- Compatible with efficient diesel combustion
- Low PM emissions, low engine noise
- Non-toxic, evaporates from water and degrades in air
- Blending with HFO tested -> lower emissions[2]



DME blending (20% & 40% wt.) with bunker oil improved performance[2]

Challenges:

- Gaseous fuel, requires special engines and infrastructure
- Viscosity and lubricity are challenging (additives needed)
- Low energy content (larger fuel tanks)
- Rarely considered in the context of maritime (in past interest for HD trucks)

1. IEA, Technology Collaboration Programme on Advanced Motor Fuels, Dimethyl ether, https://www.iea-amf.org/content/fuel_information/dme
2. Figure: Ryu, Y. and Dan, T., 2012. Combustion and emission characteristics of diesel engine by mixing DME and bunker oil. 한국마린엔지니어링학회지, 36(7), pp.885-893.
3. Makoś, P., Słupek, E., Sobczak, J., Zabrocki, D., Hupka, J. and Rogala, A., 2019. Dimethyl ether (DME) as potential environmental friendly fuel. *In E3S Web of Conferences* (Vol. 116, p. 00048). EDP Sciences.

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Agenda

1. Overview of e-fuels
2. **Current e-fuel projects in Finland: PtX**
3. Aalto University activities in the field of e-fuels

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“Veturi”- program to commercialize e-fuels

Goal: large-scale production and commercialization of e-fuels

3 key technologies:
- H_2 production through high-temp. electrolysis using a solid oxide electrolyzer cell (SOEC)
- CO_2 sequestration
- Fischer-Tropsch fuel synthesis

VTT, Neste and their partners seek breakthrough in Finnish e-fuel technology

News, Press release 08.02.2021 08:15 EET

NESTE VTT

https://www.vttresearch.com/en/news-and-ideas/vtt-neste-and-their-partners-seek-breakthrough-finnish-e-fuel-technology
https://www.neste.com/releases-and-news/innovation/nestes-veturi-partner-programme-commercialize-e-fuels

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“Veturi”- program to commercialize e-fuels

E-Fuel project is a collaborative act towards sustainable transportation fuels

https://www.e-fuel.fi/

- 2-years project, started 2021

Contact:
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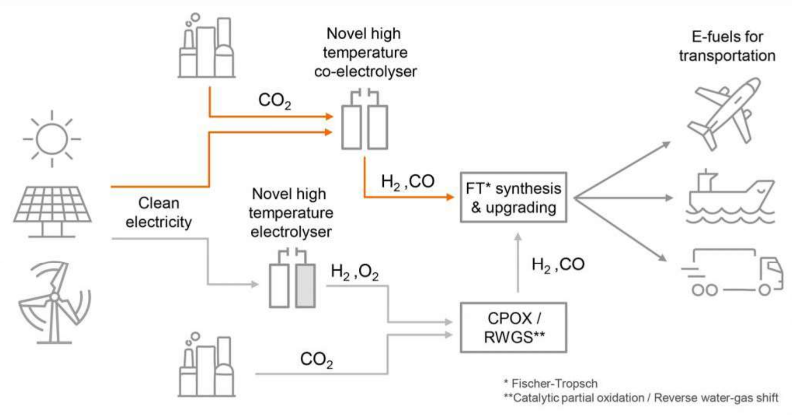
Research Professor
+358 50 4071075
juha.lehtonen@vtt.fi
https://www.e-fuel.fi/

Objectives of e-fuel "Veturi"-project

1. Development of thermal integration of solid oxide electrolysis cell (SOEC) with downstream processes
2. Optimal connection of electrolyser with power grid to maximize profit and minimize carbon emissions
3. Development of catalytic partial oxidation (CPOX)/reverse water-gas shift (RWGS) concept integration and verification of long term operation (>1000 hrs)
4. Development of integrated concept of CO_2 capture, electrolysis and FT synthesis
5. Demonstration of integrated concept in bench scale (>1000 hrs)
6. Demonstration of drop-in paraffinic e-fuel production (up to 300 kg) and usability
7. Ensuring the environmental and other impacts of e-fuel production and produced paraffinic e-fuel
8. Generating e-fuel related technology IPR for exploitation and commercialization

Main objective: demonstrate production of drop-in paraffinic e-fuels in bench scale with high efficiency by combining and integrating high temperature electrolysis and Fischer-Tropsch synthesis



Target after 2 years: 10kt/a

https://www.e-fuel.fi/

SOLETAIR pilot plant

- Pilot plant to produce hydrocarbons from CO_2
- Coupled with solar power plant
- Supported by industrial partners


Journal of CO2 Utilization
Volume 28, December 2018, Pages 235-246

Power-to-X technology using renewable electricity and carbon dioxide from ambient air: SOLETAIR proof-of-concept and improved process concept

Francisco Vidal Vázquez [a], Joonas Koponen [b], Vesa Ruuskanen [b], Cyril Bajamundi [a], Antti Kosonen [b], Pekka Simell [a], Jero Ahola [b], Christian Frilund [a], Jere Elfving [a], Matti Reinikainen [a], Niko Heikkinen [a], Juho Kauppinen [a], Paolo Piermartini [c]

- Started in 2017 and results at the end of 2018

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Project Manager
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https://soletair.fi/

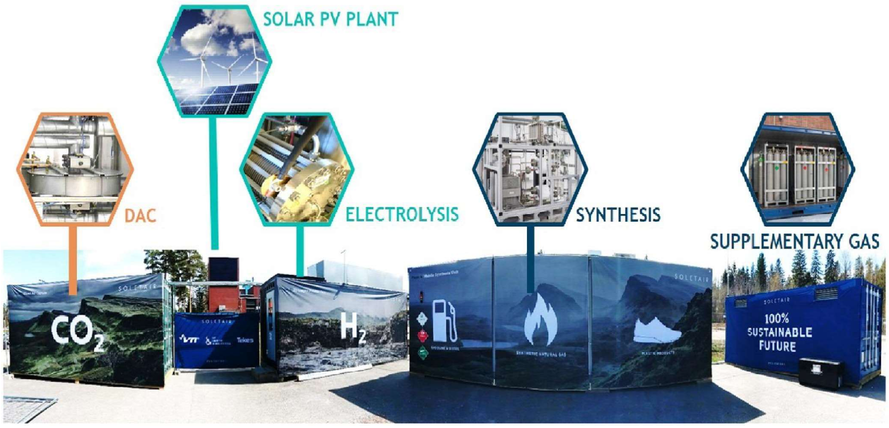
LUT Lappeenranta University of Technology

VTT

Aalto University
School of Engineering

SOLETAIR pilot plant

- Total operating time: **300h**
- Plant capacity: **6.2kg/day of oil and wax** (combined)
- Conceptual plant energy efficiency: **47%**
- Carbon efficiency: **94%**



LUT
Lappeenranta
University of Technology

VTT

Vázquez, F.V., Koponen, J., Ruuskanen, V., Bajamundi, C., Kosonen, A., Simell, P., Ahola, J., Frilund, C., Elfving, J., Reinikainen, M. and Heikkinen, N., 2018. Power-to-X technology using renewable electricity and carbon dioxide from ambient air: SOLETAIR proof-of-concept and improved process concept. *Journal of CO2 utilization*, *28*, pp.235-246.

Aalto University
School of Engineering

ICO2CHEM project

- Waste CO_2 streams from industry converted to FT products

- EU funded Horizon 2020 project, coordinated by VTT

Contact:
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Project coordinator
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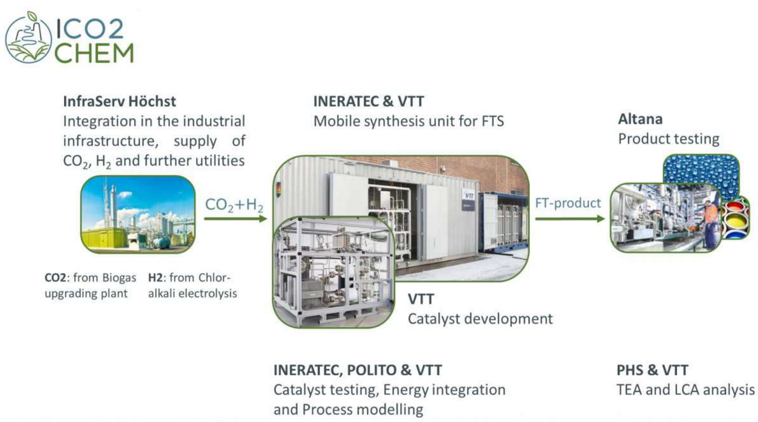
https://www.spire2030.eu/ico2chem#

ICO2CHEM is the first Power-to-Liquid plant integrated into an industrial environment

News Published on 07 December 2020

The power-to-liquid plant has been installed at the Industrial Park Höchst in Frankfurt (Main) and was approved by GTÜ (approved inspection agency). It is now the world's first Power-to-Liquid plant integrated into an industrial environment. The operating campaign aiming to produce sustainable paraffinic waxes has just started and will last until the middle of 2021.



https://www.spire2030.eu/ico2chem#

P2X project

Target: 20MW electrolysis plant for renewable H_2 production

- Feb 2021: concept design and location selection (Harjavalta, 50M EUR)
- Currently: feasibility planning phase
- Next steps: application for investment support from EU and national resources
- End of 2024: the equipment scheduled to be operational

https://p2x.fi/hanke/

Contact:
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CEO of P2X
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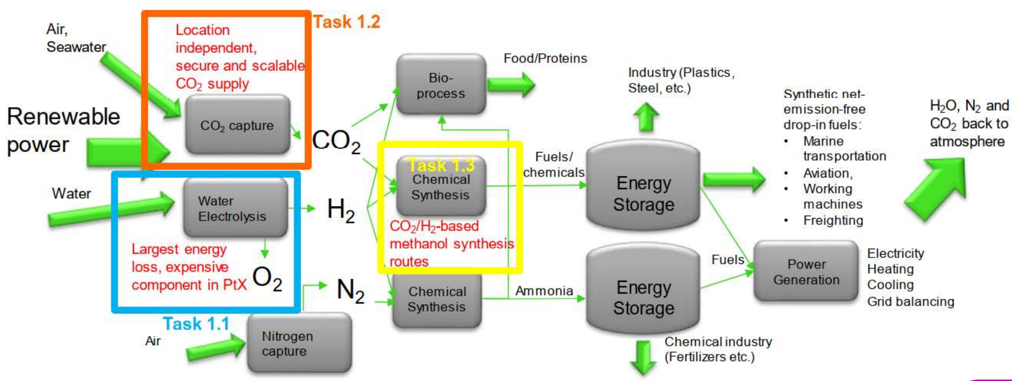
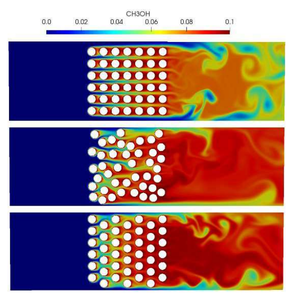
https://p2x.fi/hanke/

PtXENABLE project

- Focus on the technology development along the value chain





Task 1.3 Methanol Millireactor Improvement by modelling
https://doi.org/10.1016/j.ijhydene.2021.02.031

LUT Lappeenranta University of Technology

Wärtsilä
ABB
Solar Foods

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Agenda

1. Overview of e-fuels

2. **Current e-fuel projects in Finland: XtP**

3. Aalto University activities in the field of e-fuels

Successful methanol engine retrofit

- Retrofit of Stena Germanica by Wärtsilä
- Direct injection of methanol and ignition by pilot diesel

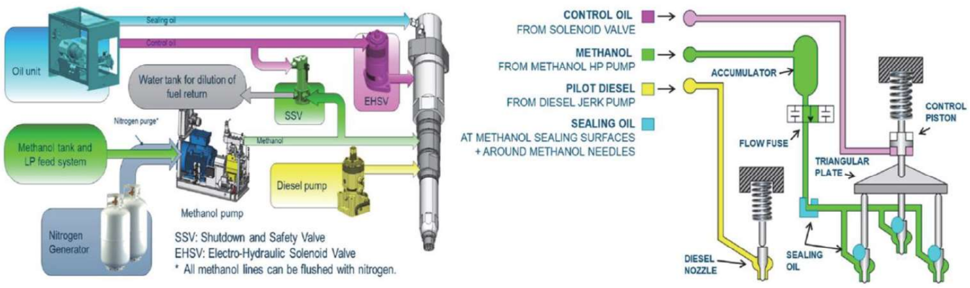
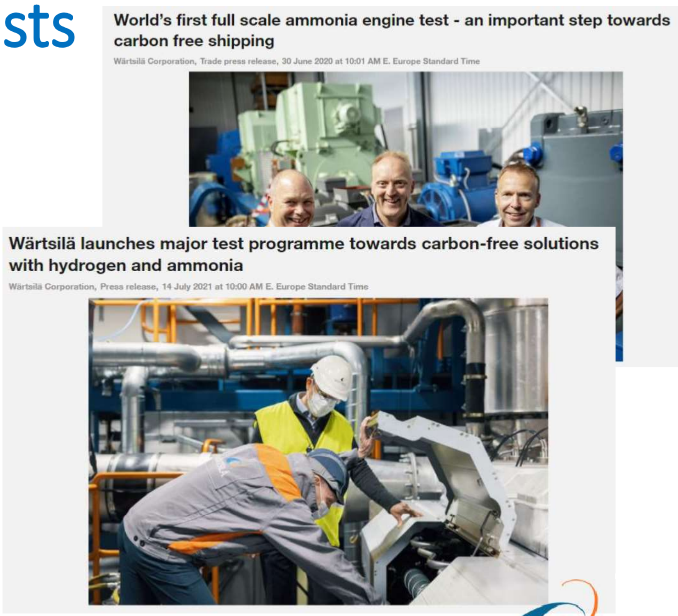


Figure 1: ZA40S methanol system layout and methanol injector working principle [1]

- Delneri, D.: "Combustion System Optimization for Alternative Fuels", 17th Conference "The Working Process of the Internal Combustion Engine", Graz 2019
- Stojcevski Toni, Jay Dave, Vincenzi Luca, "Operational experience of world's first methanol engine in a ferry installation", CIMAC congress Helsinki 2016, Paper 99

Hydrogen and ammonia tests

- Adoption of H_2 and NH_3 dependent on engine development
- Currently, advanced testing of fuel-flexible combustion engines by Wärtsilä
- Promising tests with pure hydrogen and high content of ammonia (70%)



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WÄRTSILÄ

- https://www.wartsila.com/media/news/14-07-2021-wartsila-launches-major-test-programme-towards-carbon-free-solutions-with-hydrogen-and-ammonia-2953362
- https://www.wartsila.com/media/news/30-06-2020-world-s-first-full-scale-ammonia-engine-test---an-important-step-towards-carbon-free-shipping-2737809

Hydrogen enriched compressed natural gas

- Mixing of hydrogen in compressed natural gas (CNG) using several technical options
- In the first tests at VTT (2021), hydrogen injected to gas line
  - Share of H_2 in CNG from 7 to 15 wt%.
  - Engine was running smoothly
  - NO_x emissions reduced when ratio of H2 in CNG increased

*T. Murtonen, M. Karppanen, A. Nieminen, S. Aaltonen, M. Nissilä, T. Välisalo, K. Lehtoranta, P. Aakko-Saksa - **VTT P2Move project***

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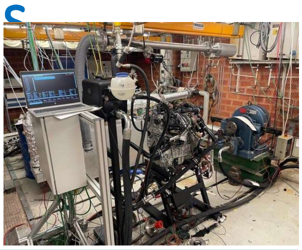
VTT



Gas engine, Mercedez-Benz

Engine designation	M270 DEH16LA*
Rated output	115 kW @ 5300 rpm
Rated torque	250 Nm @ 1250...4000 rpm
Compression ratio	10.3:1
Emissions standards	EU 5
No. of cylinders / valves	Inline 4 / 4 valves per cylinder
Tunability	Controllable standalone ECU*
Displacement	1595 cm3
Air supply	Turbocharger with charge air cooling
Boost pressure control	Electrically controlled vacuum actuator*
Boost pressure	0.7 bar
Bore	83.0 mm
Stroke	73.7 mm
Cylinder spacing	90.0 mm
Connecting rod length	152.2 mm
Injection	Sequential, intake manifold (CNG) Direct injection, optional (Gasoline)*

Aalto University
School of Engineering

Agenda

1. Overview of e-fuels
2. Current e-fuel projects in Finland
3. **Aalto University activities in the field of e-fuels**

Aalto University
School of Engineering

Powering the Future

Contact:
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Professor at Aalto
martti.larmi@aalto.fi
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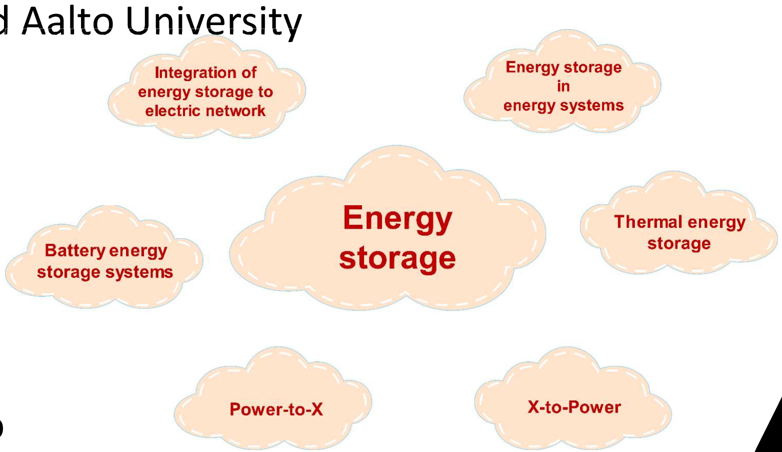
Goal: **Seeking solutions for the unbalance between supply and demand of renewable energy => development of energy storage systems**

Funding: Academy of Finland and Aalto University

Framework: academic profiling

- Prof. Martti Larmi
- Prof. Matti Lehtonen
- Prof. Sanna Syri
- Prof. Tanja Kallio
- Prof. Annukka Santasalo-Aarnio



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School of Engineering

Powering the Future: H2 electrolysis

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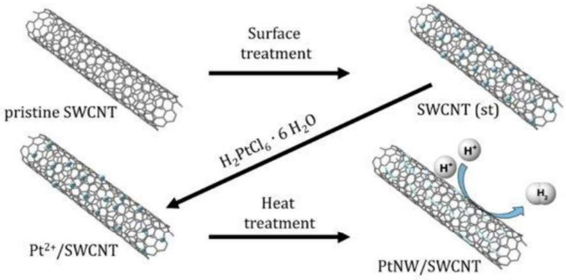
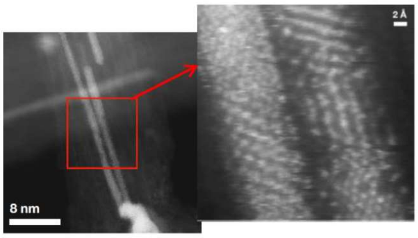
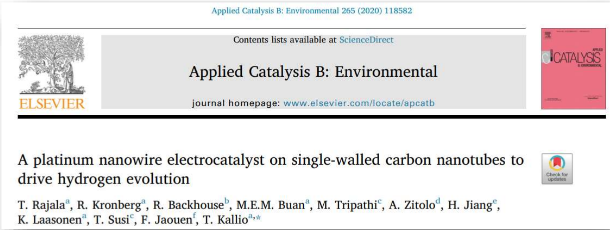
Pt/SWCNT induces high H2 production

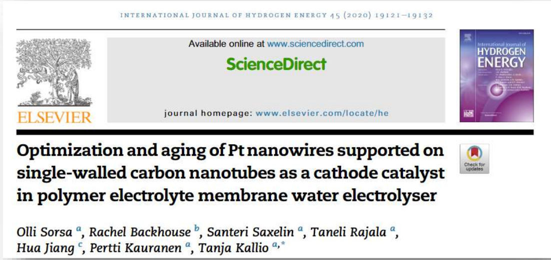





Applied Catalysis B: Environmental 265 (2020) 118582
Contents lists available at ScienceDirect
Applied Catalysis B: Environmental
journal homepage: www.elsevier.com/locate/apcatb

A platinum nanowire electrocatalyst on single-walled carbon nanotubes to drive hydrogen evolution

T. Rajala[a], R. Kronberg[a], R. Backhouse[b], M.E.M. Buan[a], M. Tripathi[c], A. Zitolo[d], H. Jiang[e], K. Laasonen[a], T. Susi[c], F. Jaouen[f], T. Kallio[a,*]


INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 45 (2020) 19121–19132
Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/he

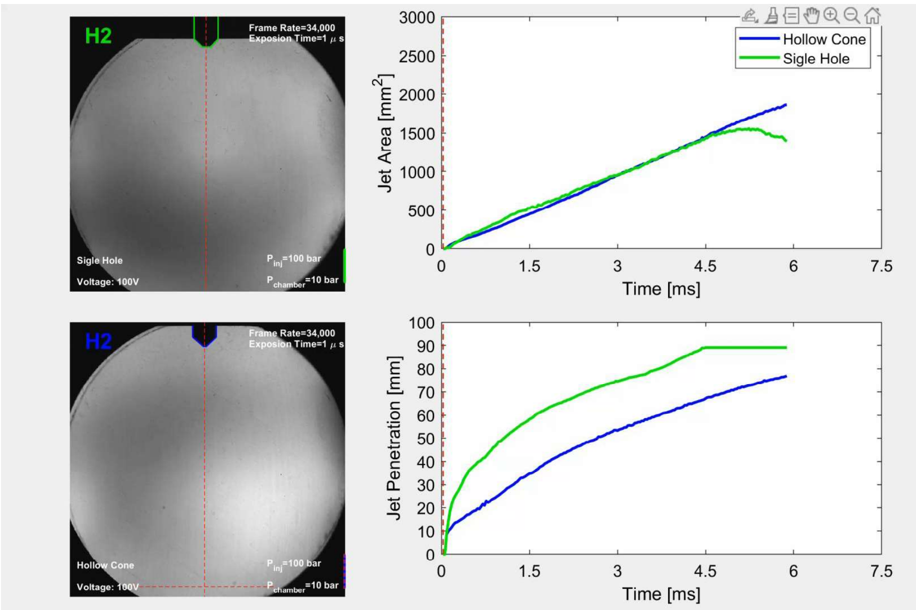
Optimization and aging of Pt nanowires supported on single-walled carbon nanotubes as a cathode catalyst in polymer electrolyte membrane water electrolyser

Olli Sorsa[a], Rachel Backhouse[b], Santeri Saxelin[a], Taneli Rajala[a], Hua Jiang[c], Pertti Kauranen[a], Tanja Kallio[a,*]

Aalto University
School of Engineering

Powering the Future: Hydrogen as a fuel

High-Speed Schlieren Imaging of Hydrogen, effect of nozzle type on the hydrogen jets



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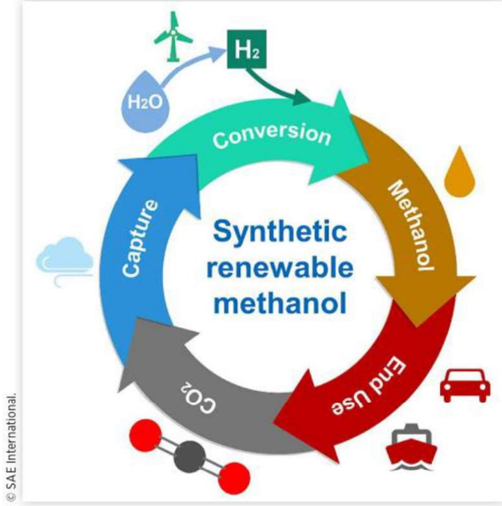
Björn Saven's donation – Methanol as Hydrogen carrier

Ambitious goals:

- ✓ **Record high energy conversion efficiency demo in 2022**
- ✓ **Strong proof for future upscaling & commercialization**



Santasalo-Aarnio, A., Nyari, J., Wojcieszyk, M., Kaario, O., Kroyan, Y., Magdeldin, M., Larmi, M. and Järvinen, M., 2020. **Application of Synthetic Renewable Methanol to Power the Future Propulsion** (No. 2020-01-2151). *SAE Technical Paper*. DOI: https://doi.org/10.4271/2020-01-2151

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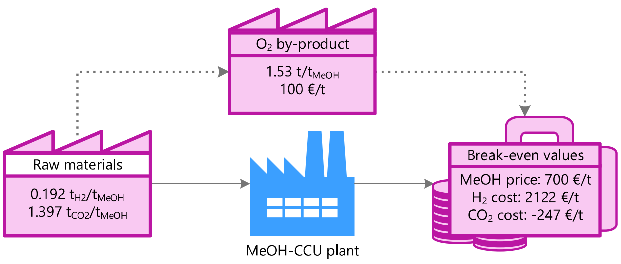
https://www.aalto.fi/en/news/bjorn-savens-donation-to-aalto-university-makes-a-significant-contribution-to-hydrogen

Methanol as Hydrogen carrier: Power-to-Methanol

Journal of CO_2 Utilization 39 (2020) 101166
Contents lists available at ScienceDirect
Journal of CO_2 Utilization
journal homepage: www.elsevier.com/locate/jcou

Techno-economic barriers of an industrial-scale methanol CCU-plant

Judit Nyári, Mohamed Magdeldin, Martti Larmi, Mika Järvinen, Annukka Santasalo-Aarnio*
Research Group of Energy Conversion, Department of Mechanical Engineering, School of Engineering, Aalto University, PO Box 14400, FI-00076 AALTO, Finland



INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 46 (2021) 15635–15648
Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/he

A numerical performance study of a fixed-bed reactor for methanol synthesis by CO_2 hydrogenation

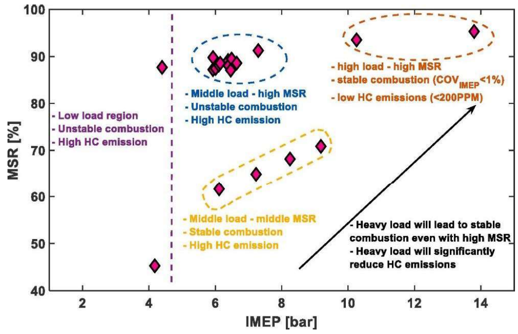
Daulet Izbassarov [a,*], *Judit Nyári* [a], *Bulut Tekgül* [a], *Erkki Laurila* [a], *Tanja Kallio* [b], *Annukka Santasalo-Aarnio* [a], *Ossi Kaario* [a], *Ville Vuorinen* [a]
[a] *Department of Mechanical Engineering, Aalto University, FI-00076, Espoo, Finland*
[b] *Department of Chemistry and Materials Science, Aalto University, FI-00076, Espoo, Finland*

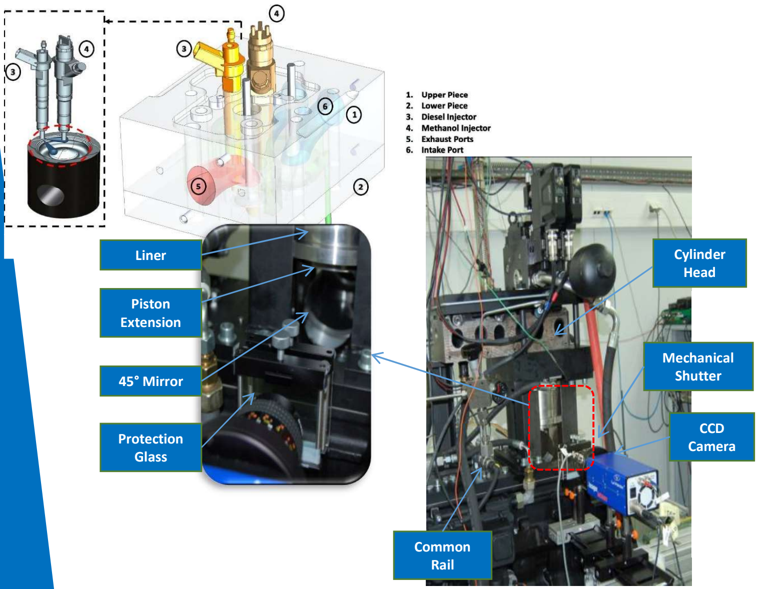
Laboratory set-up for MeOH synthesis

Methanol as Hydrogen carrier: Methanol to Power

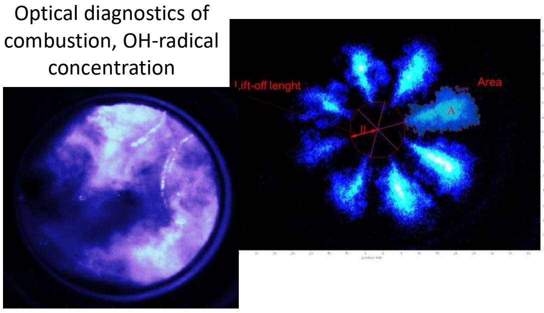
Aalto University
School of Engineering

High efficiency combustion possible with new dual fuel technologies





Optical diagnostics of combustion, OH-radical concentration



Dong, Y., Kaario, O., Hassan, G., Ranta, O., Larmi, M. and Johansson, B., 2020. High-pressure direct injection of methanol and pilot diesel: A non-premixed dual-fuel engine concept. *Fuel*, 277, p.117932, DOI: https://doi.org/10.1016/j.fuel.2020.117932

Tri fuel combustion: pilot ignited methane with hydrogen enrichment

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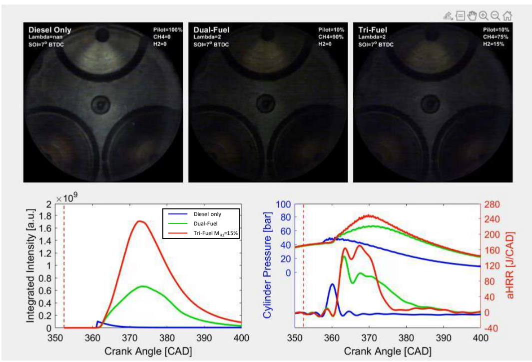
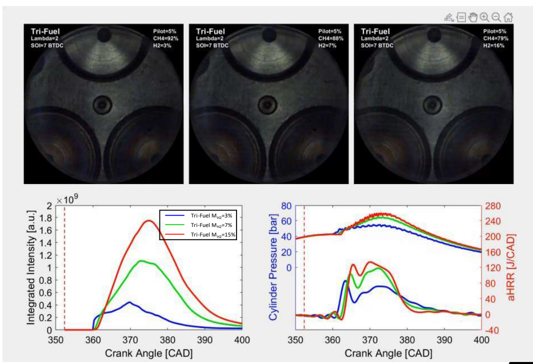
Experimental Setup

Comparison of Diesel-only, DF and TF combustion



Note: the diesel-only mode, we use the same amount of diesel as used in DF and TF mode.

Comparison of TF combustion with various H2 concentration



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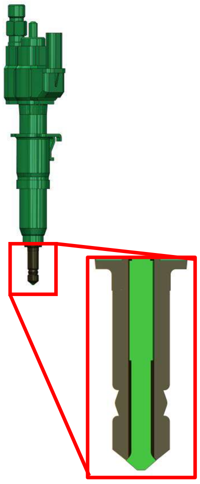
School of Engineering

CAHEMA project

Aim (at Aalto): Experimental characterization of ammonia combustion

Current research:
- Ammonia optical engine tests
- Ammonia + diesel pilot
- Ammonia + H_2 + diesel pilot
- Dual-fuel/Tri-Fuel/RCCI



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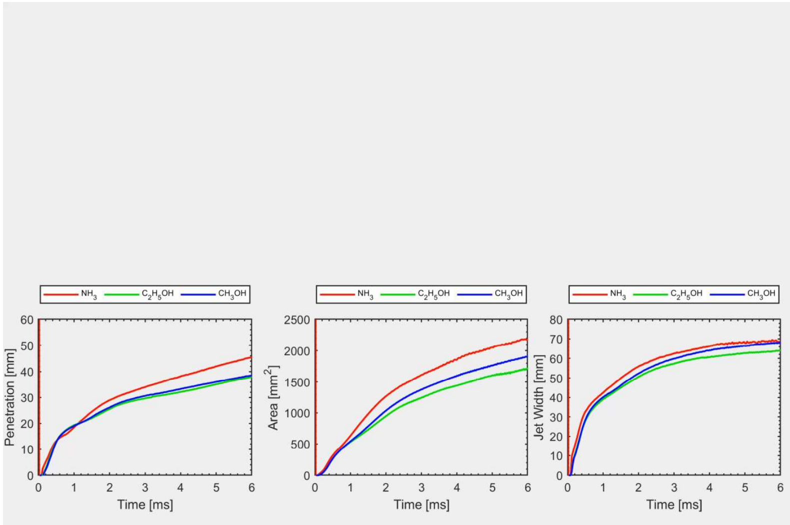
Ammonia spray characteristics



Aalto University
School of Engineering

AdvanceFuel (End-use performance assessment)

- www.advancefuel.eu
- H2020 EU project
- Transport fuel candidates in various transport sectors

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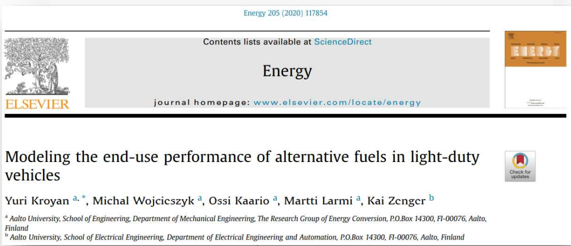

Energy 205 (2020) 117854

Contents lists available at ScienceDirect

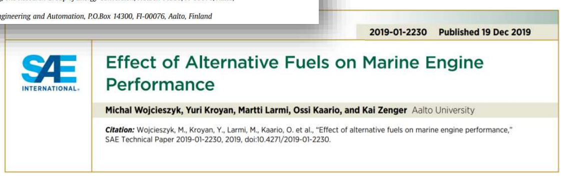
Energy

journal homepage: www.elsevier.com/locate/energy

Modeling the end-use performance of alternative fuels in light-duty vehicles

Yuri Kroyan [a,*], Michal Wojcieszyk [a], Ossi Kaario [a], Martti Larmi [a], Kai Zenger [b]

[a] Aalto University, School of Engineering, Department of Mechanical Engineering, The Research Group of Energy Conversion, P.O.Box 14300, FI-00076, Aalto, Finland
[b] Aalto University, School of Electrical Engineering, Department of Electrical Engineering and Automation, P.O.Box 14300, FI-00076, Aalto, Finland


2019-01-2230 Published 19 Dec 2019

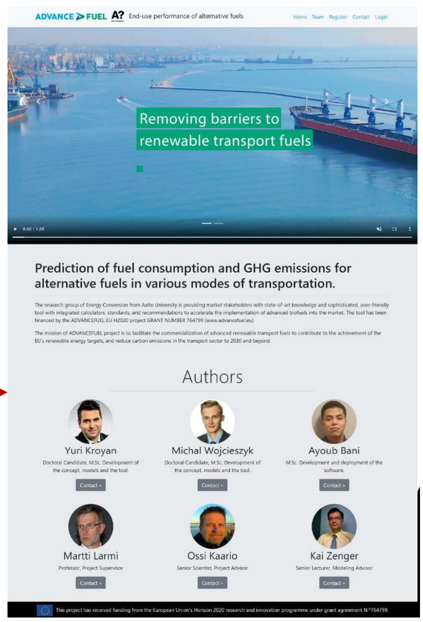
Effect of Alternative Fuels on Marine Engine Performance

Michal Wojcieszyk, Yuri Kroyan, Martti Larmi, Ossi Kaario, and Kai Zenger Aalto University

Citation: Wojcieszyk, M., Kroyan, Y., Larmi, M., Kaario, O. et al., "Effect of alternative fuels on marine engine performance," SAE Technical Paper 2019-01-2230, 2019, doi:10.4271/2019-01-2230.

THE ONLINE TOOL

advancefuel.aalto.fi



Conclusions and take away

1. Large company driven and academic activities on PtX: hydrogen production, CO2 sequestration, fuel synthesis
2. Large company driven and academic activities on XtP, especially for marine and off-road sectors: methanol, neat hydrogen, methane-hydrogen blends, ammonia

Thank You for your attention!

Questions, answers, and comments

Q. Any experiences (robustness, tribology, oil interactions…)of methanol usage in shipments, ferry, or any else? Is it too early to apply?

A. We have been running the methanol engine in such way. We have experiences on the oil. My feeling is that we should have to use different kind of oil specification. Otherwise, I'm not very concerned about methanol usage. Methanol combustion is pretty doable. We are working on port-fuel methanol injection (not published).

C. Comment with the methanol combustion. Port-fuel injection or early direct injection, lots of communication with lubrication oil. Then fuel, lubrication oil interaction will be quite severe. Otherwise, interaction with lubrication oil will be much smaller.

An efficient way of e-fuel production

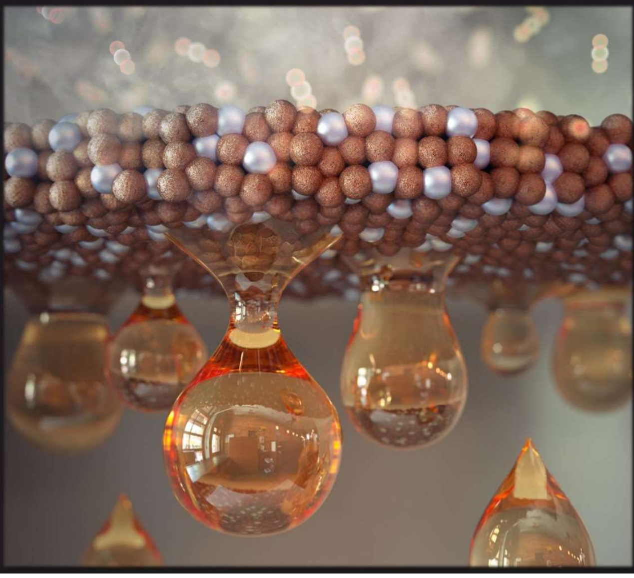
Seok Ki Kim

Korea Research Institute of Chemical Technology

About the speaker:

- Senior Research Scientist at KRICT, Republic of Korea
- PhD at Seoul National University
- Postdoctoral research career at Korea Institute of Science and Technology (KIST) and Brown University

An Efficient Way of e-fuel Production



ReFuel 2021

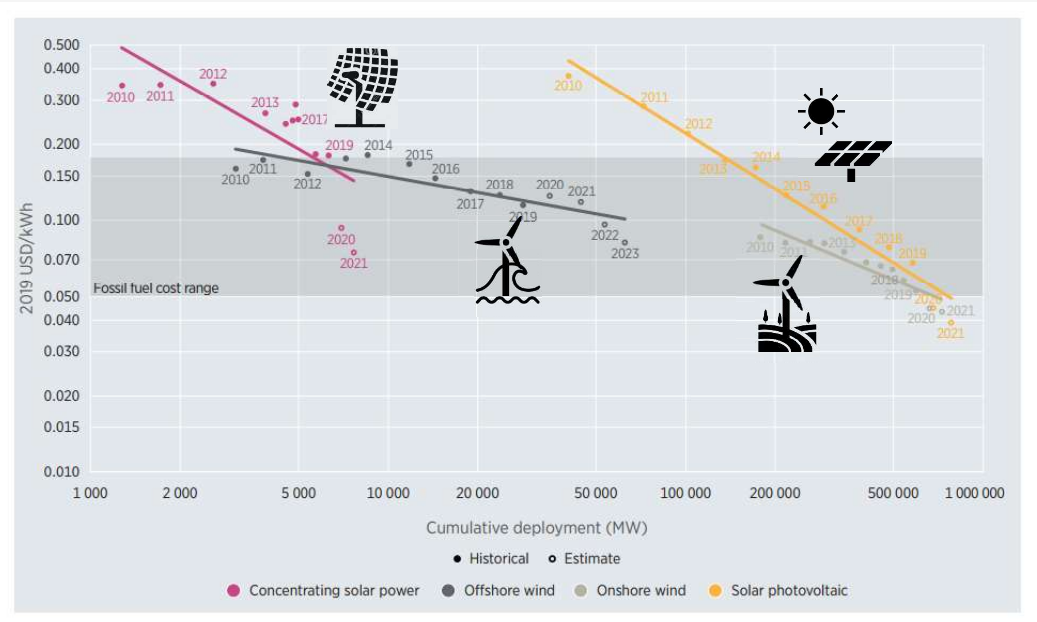
Korea Research Institute of Chemical Technology (KRICT)

Seok Ki Kim

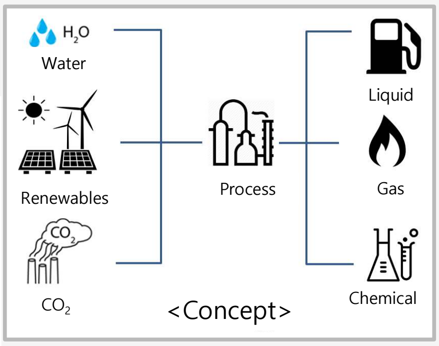
Contents

Introduction	Process	Catalyst	Scale up	Acknowledgement
• Power-to-X • Energies • Density comparison	• Demo plants • Direct vs Indirect • PtL+PtG hybrid	• Catalyst for direct process • Theory	• Pilot plant • Product distribution • Summary	• Contributions • Funding

Introduction: Power-to-X

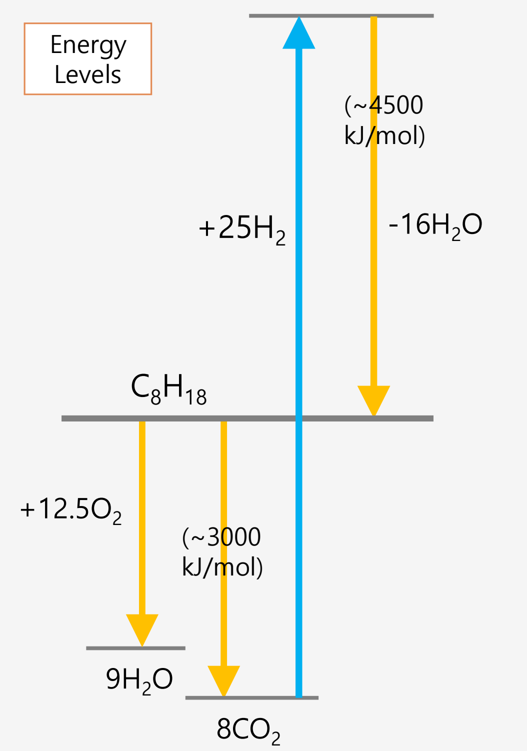


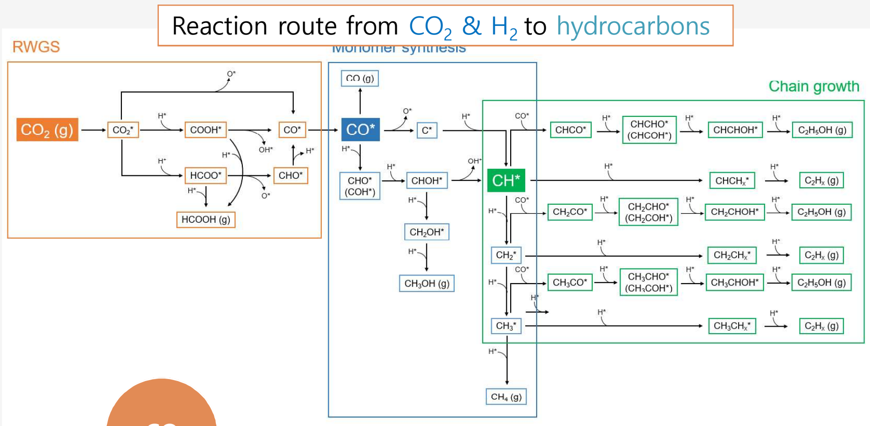
Source: IRENA Power Generation Costs (2019)

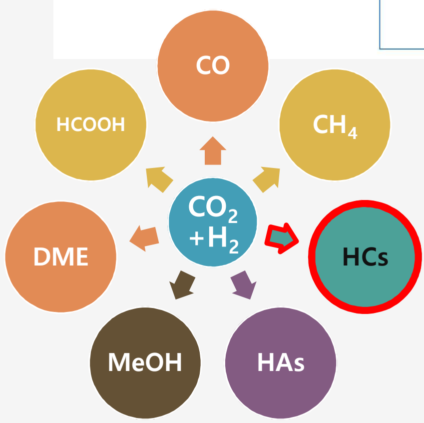


- **Power to X:**
  A process producing chemicals using renewable power
- **Carbon-neutral cycle implemented**
- **Large-scale renewable energy storage**
- **Energy-efficient process required**

Introduction: Energy & Catalysis

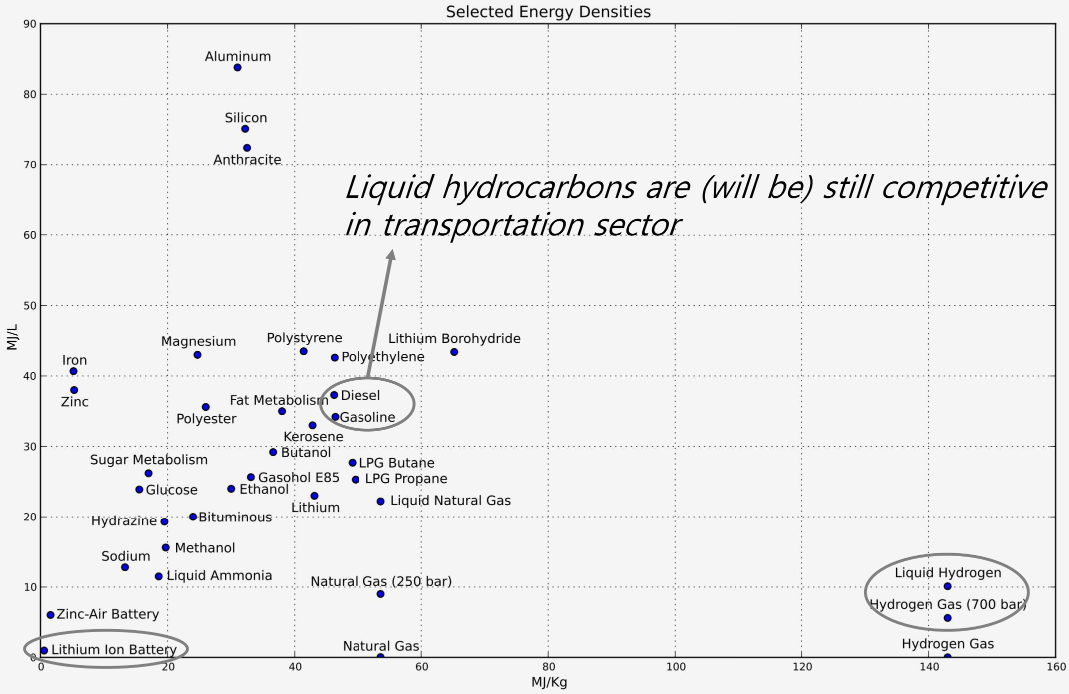






- **Large amount of H_2 energy required**
- **Techno-economic competitiveness depends on H_2 supply**
- **Various products can be obtained**
- **Reaction route control by catalyst**

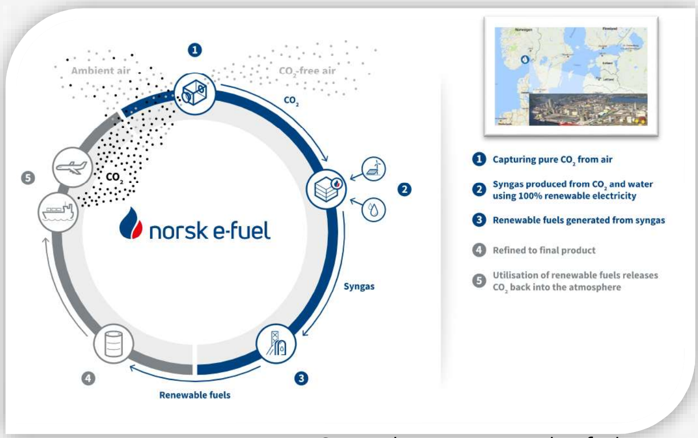
Energy density comparison



https://en.wikipedia.org/wiki/Energy_density

5

PtX demonstration



Source: https://www.norsk-e-fuel.com/

Source: https://www.porsche.com/

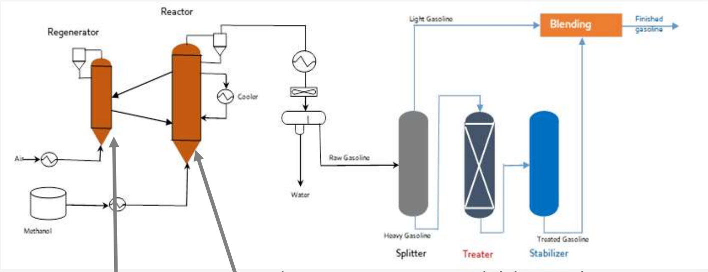
- **Norsk e-fuel**:
  - ✓ Solid oxide electrolyzer cell (SOEC, H_2)
  - ✓ Direct Air Capture (DAC, CO_2)
  - ✓ Reverse water-gas shift (RWGS, CO)
  - ✓ Fischer-Tropsch synthesis (FTS, Liquid fuel)
- e-fuel production scale ~100 million liter/year
- CO_2 reduction rate ~ 250,000 ton/year at 2026

- **Porsche-SIEMENS**:
  - ✓ Proton exchange membrane electrolysis (PEM, H_2)
  - ✓ Direct Air Capture (DAC, CO_2)
  - ✓ Methanol synthesis (CH_3OH)
  - ✓ Methanol-to-Gasoline (MTG, gasoline)
- Started to build the e-fuel plant in Chile
- e-fuel production scale ~ 500 million liter/year at 2026

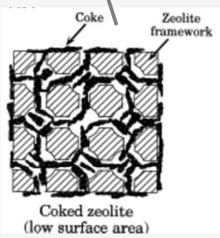
6

PtX demonstration

Methanol-to-Gasoline process (Fluidized)



Source: https://www.exxonmobilchemical.com



- Low T operation (< 350)
- Narrow HC distribution
- Zeolites show fast deactivation by coking

- Regeneration: Coke burning ($C + O_2 \rightarrow CO_2$)

Low carbon efficiency

Source: https://www.porsche.com/

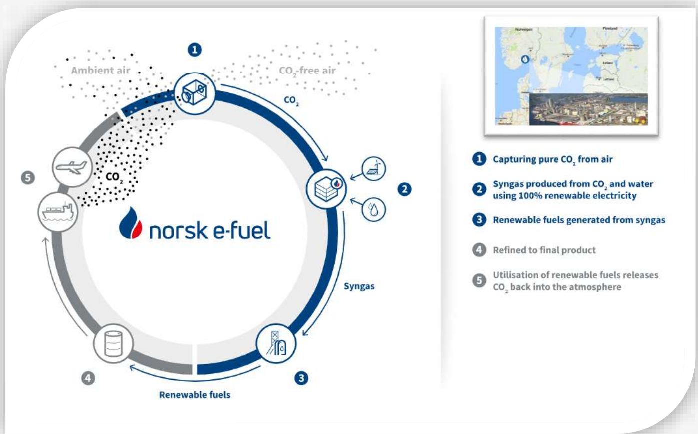
- **Porsche-SIEMENS**:

✓ Proton exchange membrane electrolysis (PEM, H_2)
✓ Direct Air Capture (DAC, CO_2)
✓ Methanol synthesis (CH_3OH)
✓ **Methanol-to-Gasoline (MTG, gasoline)**

- Started to build the e-fuel plant in Chile
- e-fuel production scale ~ 500 million liter/year at 2026

7

PtX demonstration



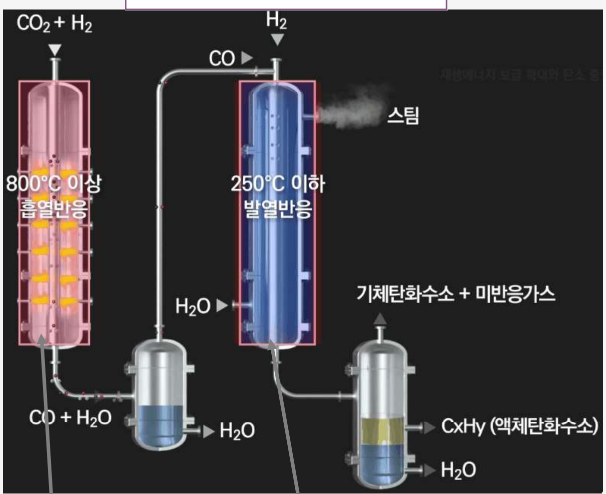
Source: https://www.norsk-e-fuel.com/

- **Norsk e-fuel**:

✓ Solid oxide electrolyzer cell (SOEC, H_2)
✓ Direct Air Capture (DAC, CO_2)
✓ **Reverse water-gas shift (RWGS, CO)**
✓ **Fischer-Tropsch synthesis (FTS, Liquid fuel)**

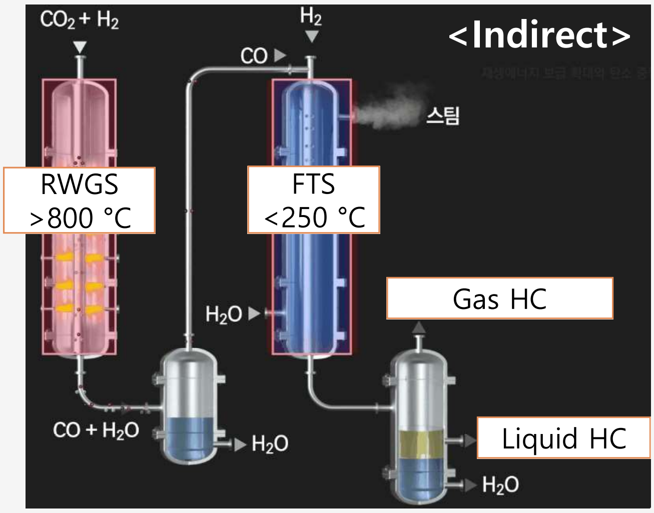
- e-fuel production scale ~100 million liter/year
- CO_2 reduction rate ~ 250,000 ton/year at 2026

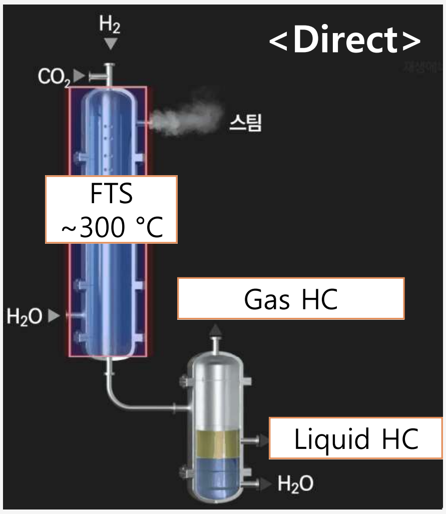
RWGS + FTS combination



- RWGS: High CO_2 conversion
- FTS: Broad HC distribution
- High T + Low T is disadvantageous to energy efficiency
- Co-catalyzed FTS requires additional upgrading process

Indirect vs Direct





Method	Catalyst	Process	TRL	Characteristics
Indirect	Co	RWGS+FTS	7-8	• High yield • Low energy efficiency
Direct	Fe	(CO_2)FTS	3-5	• High energy efficiency • Low yield

9

Indirect vs Direct (+PtG)

Comparison of P2L and P2G

Item	P2L	P2G
Product revenue	Higher	Lower
Product energy density	Higher	Lower
Product storage & transportation	Easier	Harder
Main reaction	Fischer-Tropsch	Methanation
Conversion in the reaction	Incomplete	Complete
Selectivity in the reaction	Lower	Higher
Byproducts in the reaction	Gaseous HC, CO	-
Reactor	Iso-thermal	Simpler

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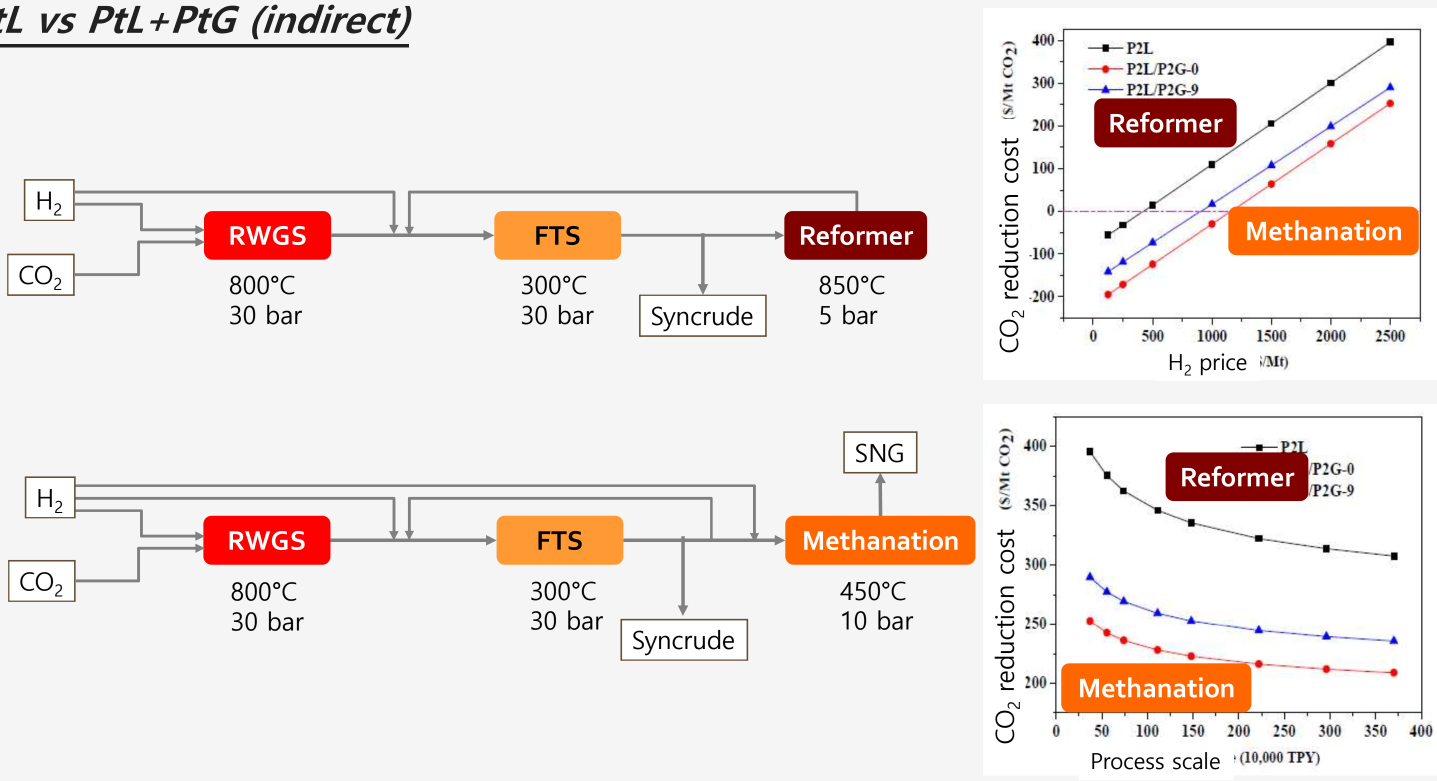
PtL vs PtL+PtG (indirect)



Fuel 291 (2021) 120111

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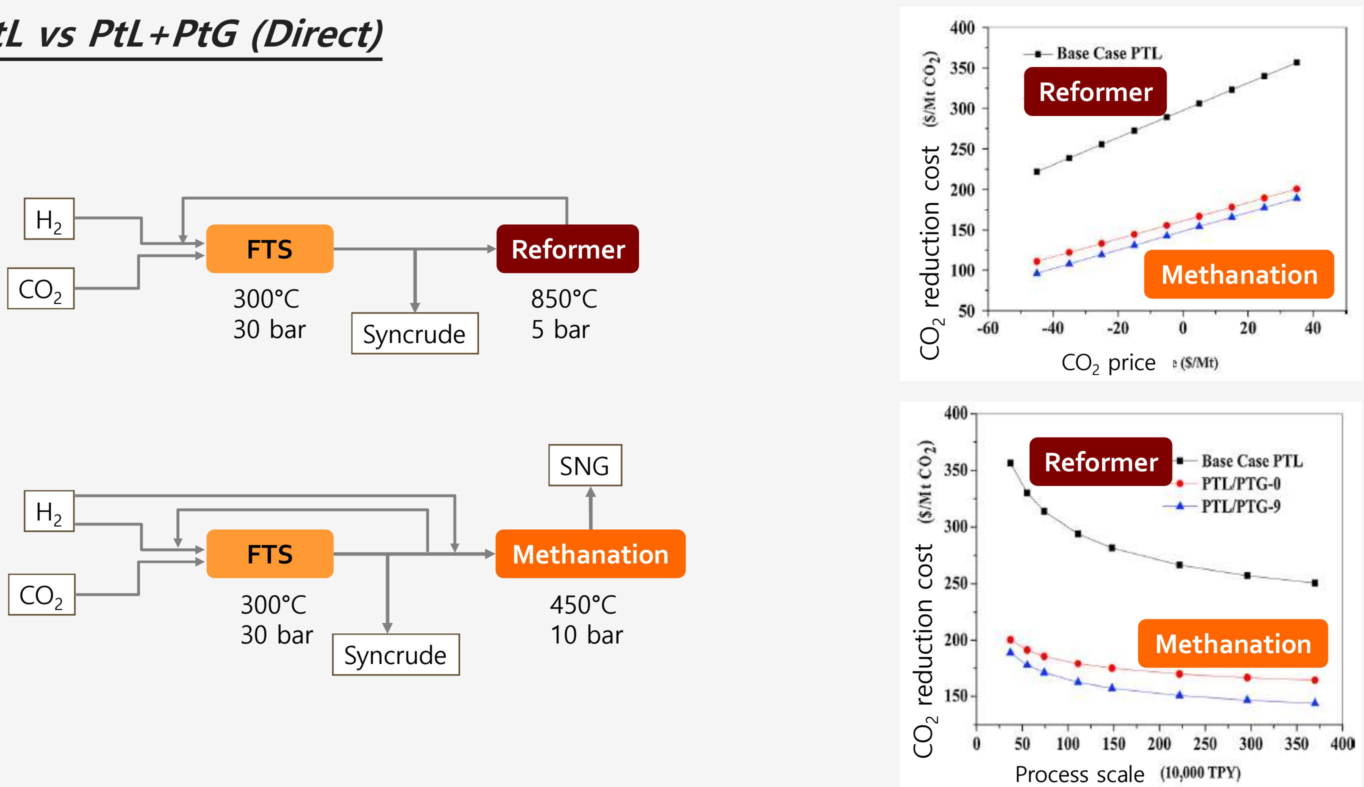
PtL vs PtL+PtG (Direct)



J. CO2 Util. 34 (2019) 293-302

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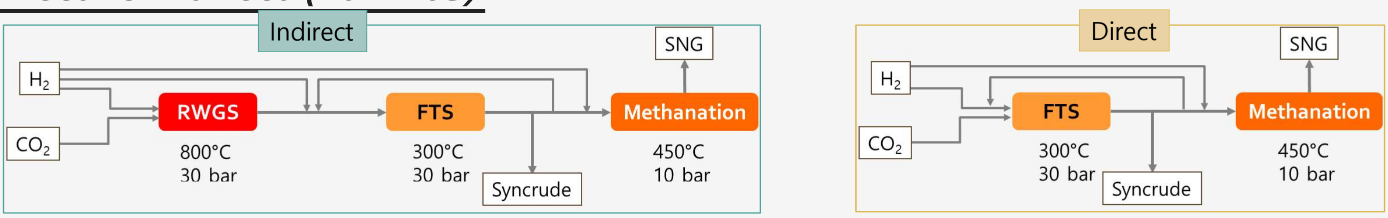
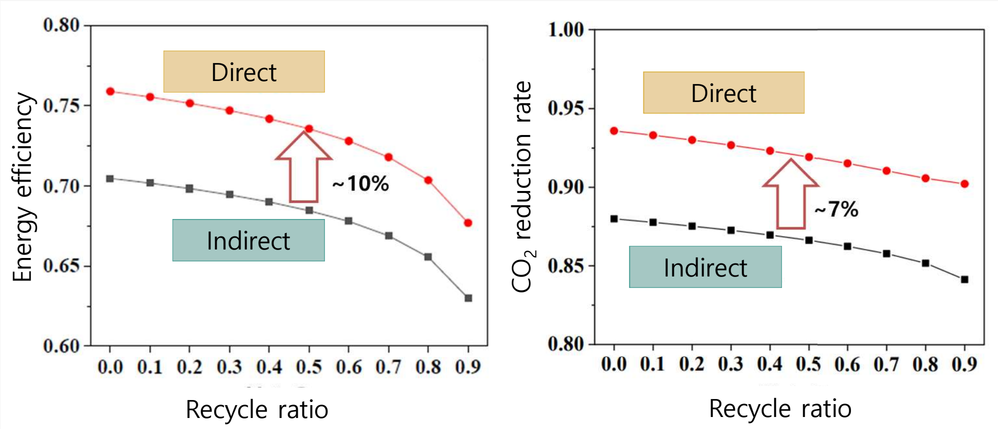
Direct vs Indirect (PtL+PtG)





- Direct process shows higher energy efficiency and CO_2 reduction rate

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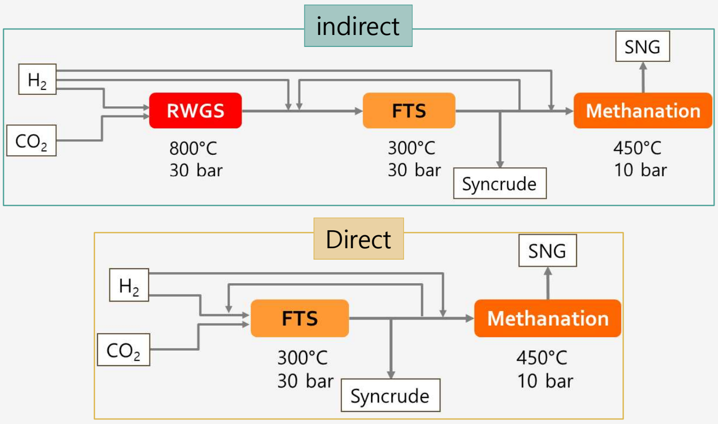
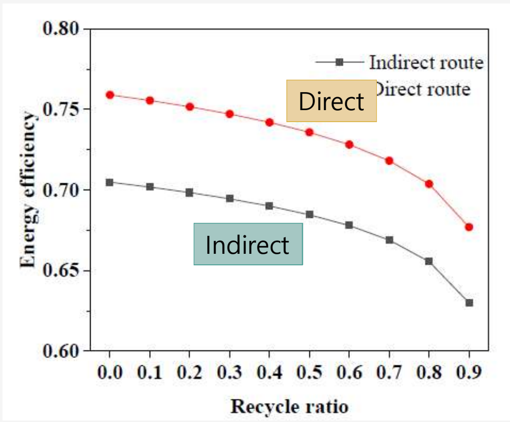
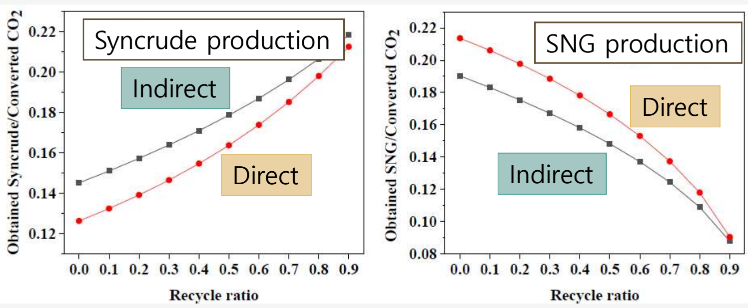
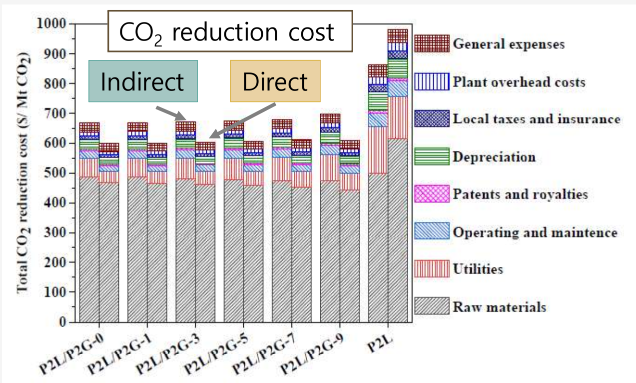
Direct vs Indirect (PtL+PtG)









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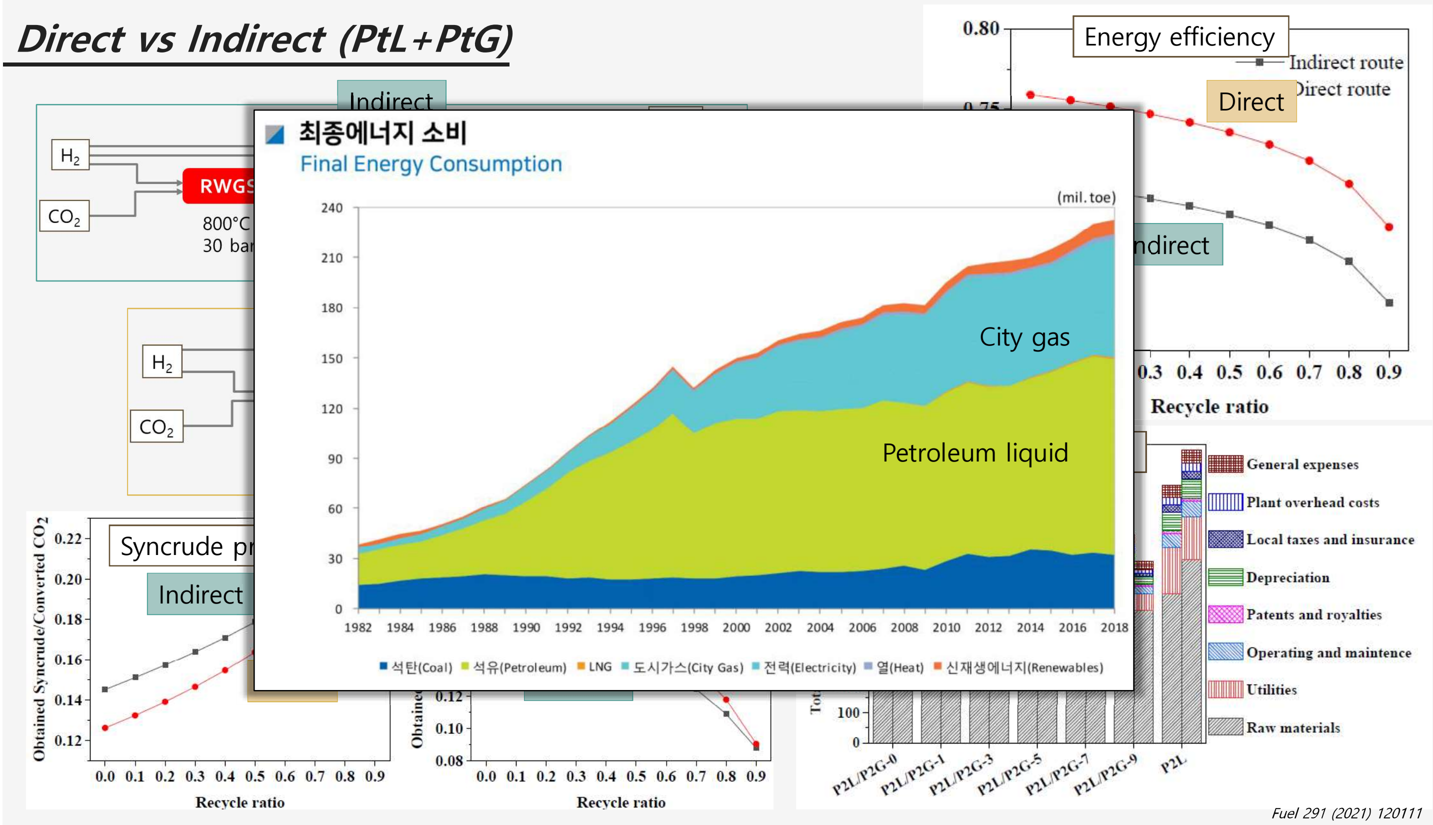
Direct vs Indirect (PtL+PtG)



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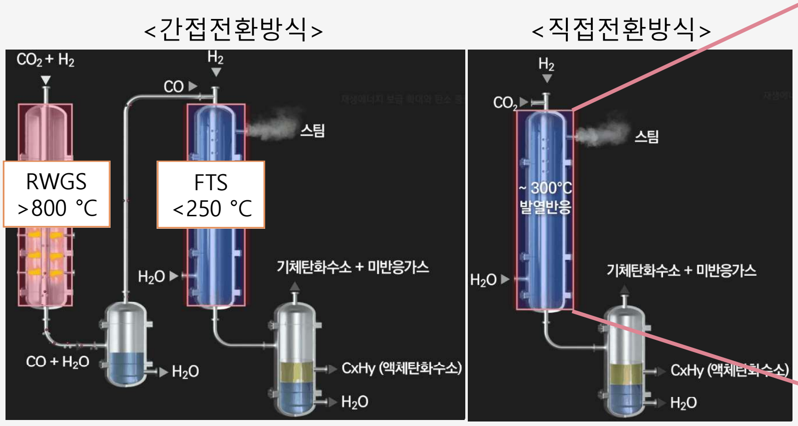
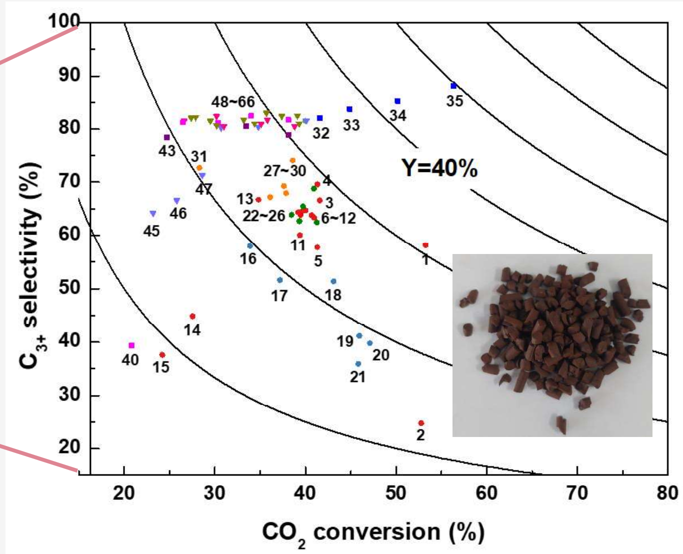
Direct process catalysts: Fe+X+Y+Z





1. Co/KFe/AC
2. Ni-KFe/AC
3. Ag-KFe/AC
4. Cu-KFe/AC
5. Fe/AC
6. KFe/AC
7. Ba-KFe/AC
8. Zn-KFe/AC
9. Ca-KFe/AC
10. Mn-KFe/AC
11. Ce-KFe/AC
12. W-KFe/AC
13. Ga-KFe/AC
14. In-KFe/AC
15. B-KFe/AC
16. Fe-Al-K
17. Fe-Co-Al-K (Fe-Co=95:5)
18. Fe-Co-Al-K (Fe-Co=90:10)
19. Fe-Co-Al-K (Fe-Co=80:20)
20. Fe-Co-Al-K (Fe-Co=70:30)
21. Fe-Co-Al-K (Fe-Co=50:50)
22. Fe-Cu-Al-K (Fe-Cu=95:5)
23. Fe-Cu-Al-K (Fe-Cu=90:10)
24. Fe-Cu-Al-K (Fe-Cu=80:20)
25. Fe-Cu-Al-K (Fe-Cu=70:30)
26. Fe-Cu-Al-K (Fe-Cu=50:50)
27. Fe-Zn-Al-K (Fe-Zn=95:5)
28. Fe-Zn-Al-K (Fe-Zn=90:10)
29. Fe-Zn-Al-K (Fe-Zn=80:20)
30. Fe-Zn-Al-K (Fe-Zn=70:30)
31. Fe-Zn-Al-K (Fe-Zn=50:50)
32. KRICT (K) powder SV 4500
33. KRICT (K) powder SV 3000
34. KRICT (K) powder SV 1800
35. KRICT (K) powder SV 900
36. DAT (K) powder SV 4500
37. DAT (K) powder SV 3000
38. DAT (K) powder SV 1500
39. DAT (K) powder SV 1000
40. DAT 1.2C (K) powder SV 4500
41. DAT 1.2C (K) powder SV 4500
42. KITECH (K) powder SV 4500
43. KITECH (K) Fe-Cu powder SV 4500
44. KITECH (K) Fe oxide powder SV 4500
45. KRICT extruder SV 4500
46. KRICT extruder SV 3000
47. KRICT extruder SV 1500
48. KRICT (K) extruder SV 4500
49. KRICT (K) extruder SV 3000
50. KRICT (K) extruder SV 1500
51. core-shell (K) 3mm SV 4500
52. core-shell (K) 3mm SV 3000
53. core-shell (K) 3mm SV 1500
54. core-shell (K) 2mm SV 4500
55. core-shell (K) 2mm SV 3000
56. core-shell (K) 2mm SV 1500
57. CMT (K) 2mm 550 cal. SV 4500
58. CMT (K) 2mm 550 cal. SV 3000
59. CMT (K) 2mm 550 cal. SV 1500
60. CMT (K) 2mm 600 cal. SV 4500
61. CMT (K) 2mm 600 cal. SV 4500
62. CMT (K) 2mm 600 cal. SV 4500
63. CMT (K) 3mm 500 red. SV 4500
64. CMT (K) 3mm 500 red. SV 1500
65. CMT (K) 3mm 300 red. SV 4500
66. CMT (K) 3mm 300 red. SV 1500

- Fe-based catalysts
- Second metal species, amount, pellet type.... Variables!

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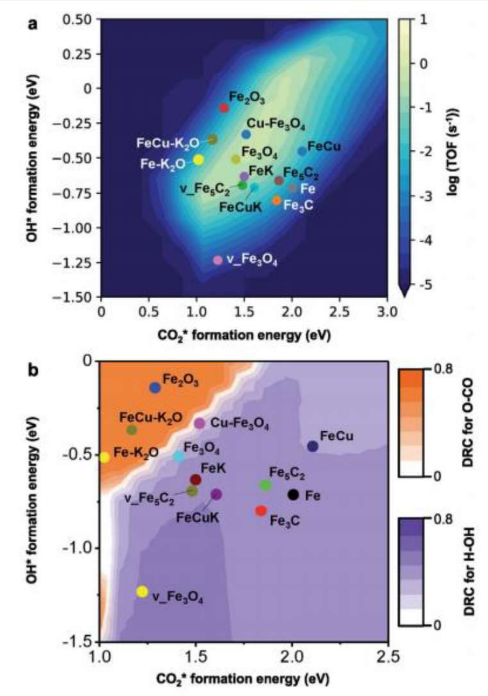
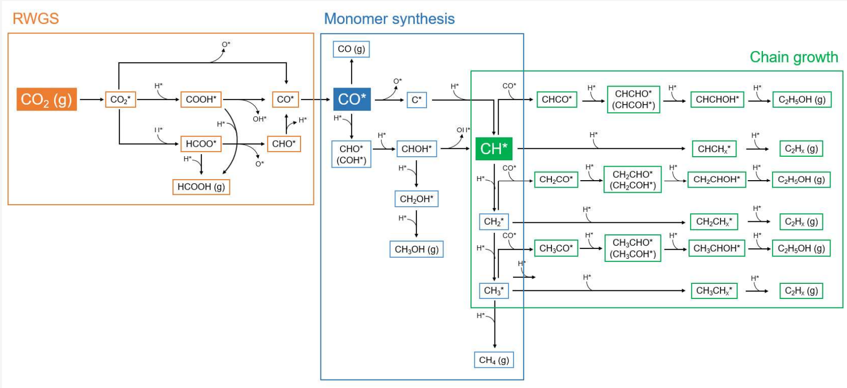
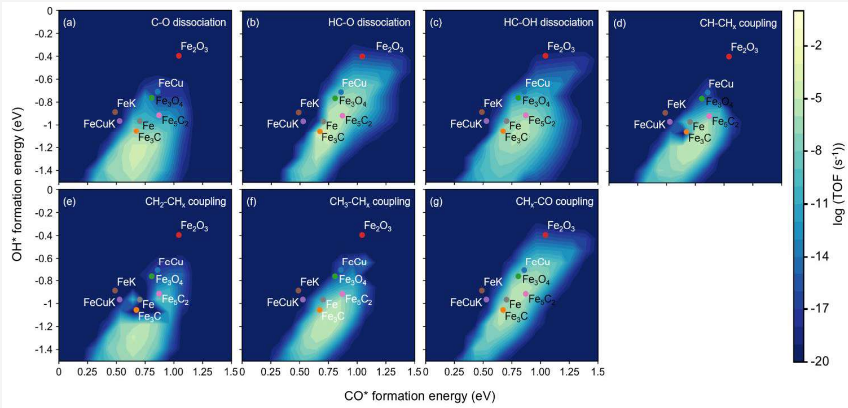
Theoretical estimation



J. Mater. Chem. A 8 (2020)13014–13023





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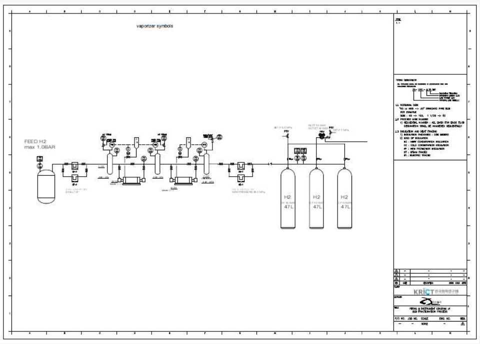
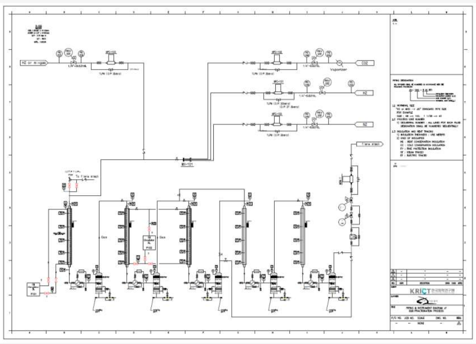
Mini-pilot operation





- **5 kg/day scale PtG+PtL hybrid plant**
- **AEM electrolysis**

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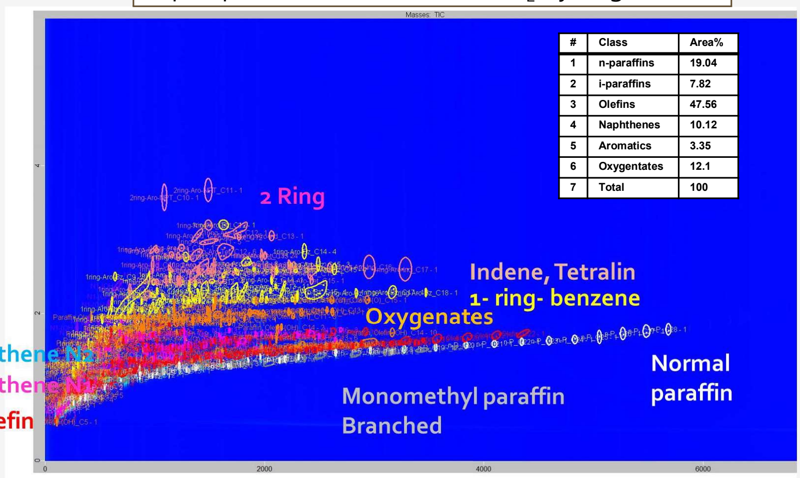
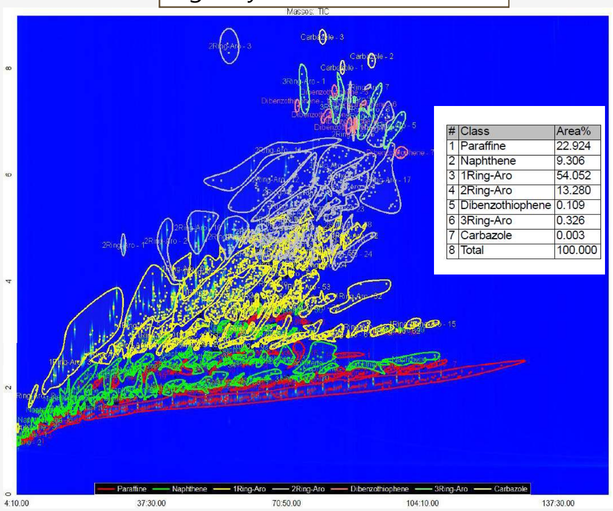
Product analysis

Liquid product obtained from CO_2 hydrogenation



Light cycle oil from FCC unit



CO_2 hydrogenation (Fe catalyzed)	Petroleum
Olefin, oxygenate rich	Aromatics rich

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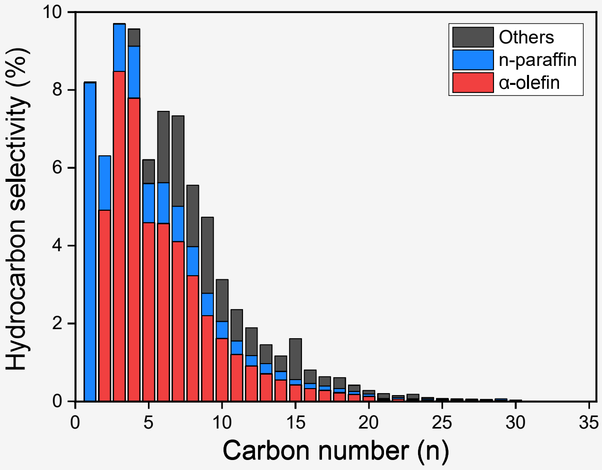
Product analysis



Total paraffin selectivity (%)	**31.1**
n-paraffin	*18.7*
branched-paraffin	*12.4*
Total olefin selectivity (%)	**49.2**
1-olefin	*46.9*
internal-olefin	*0.5*
branched olefin	*1.8*
Olefin distribution in C2-C4 (%)	**84.3**
Olefin distribution in C5-C20 (%)	**61.0**
Mass balance (%)	**93.7**

CO_2 conversion (%)	CO selectivity (%)	Molar carbon distribution (%)					Oxygenate Selectivity (%)	α
		CH_4	$C_2^=$-$C_4^=$	C_2^0-C_4^0	C5+	Wax (C30+)		
39.7	7.6	9.7	25.5	4.7	55.0	5.1	12.1	0.73

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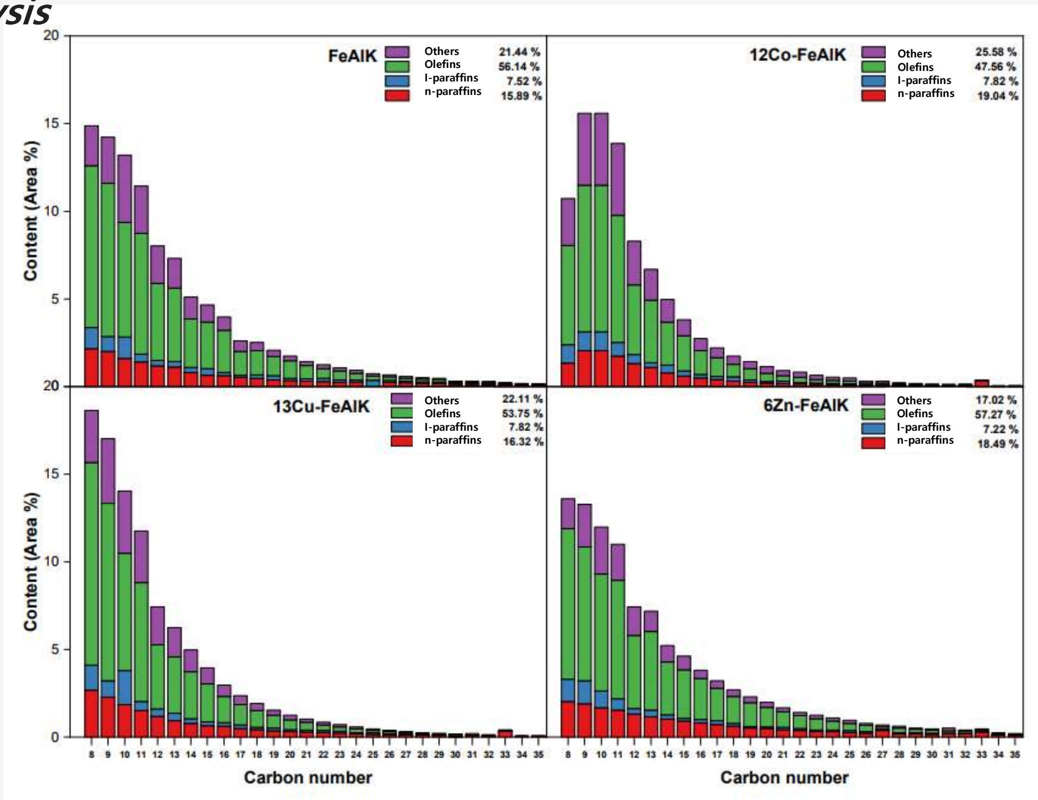
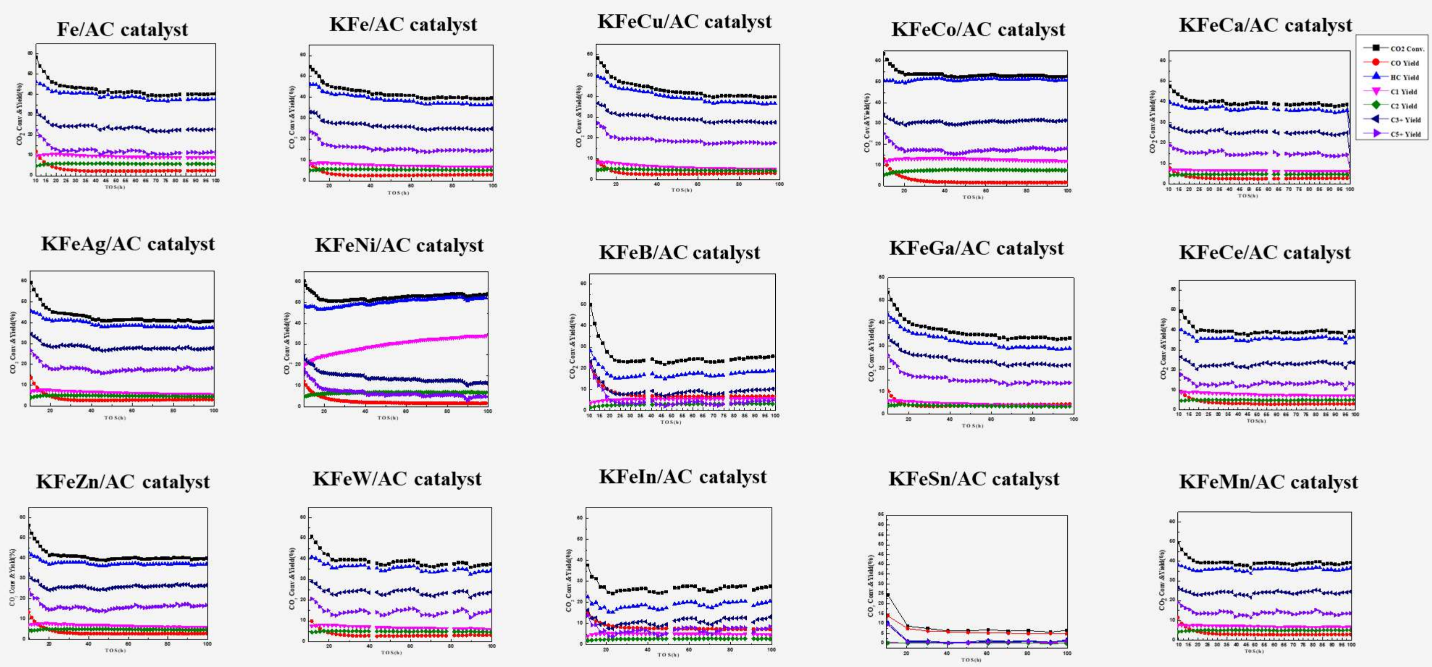
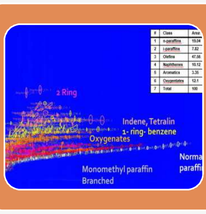
Product analysis



Deactivation test

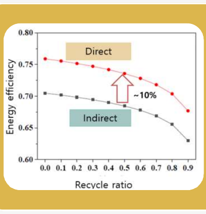


Summary



Compatibility

- E-fuel has high energy density
- Large scale CO2 reduction available



Production

- Direct hydrogenation is energy-efficient
- SNG production increases economic feasibility

KRICT catalyst process

- > 40% yield catalyst was developed
- 5 kg/day pilot plant is being demonstrated

References

- Sun-Mi Hwang, Seung Ju Han, Hae-Gu Park, Hojeong Lee, Kwangjin An, Ki-Won Jun,* Seok Ki Kim*
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ACS Catalysis, 11, 2267-2278 (2021)

- Ruxing Gao, Chundong Zhang, Ki-Won Jun, Seok Ki Kim, Hae-Gu Park, Tiansheng Zhao, Lei Wang, Hui Wan, Guofeng Guan
"Transformation of CO_2 into liquid fuels and synthetic natural gas using green hydrogen: A comparative analysis"
Fuel, 291, 120111 (2021)

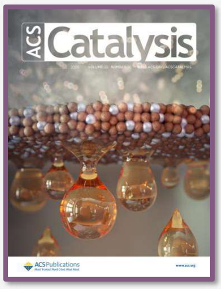
- Kwang Young Kim, Hojeong Lee, Woo Yeong Noh, Jungho Shin, Seung Ju Han, Seok Ki Kim, Kwangjin An*, Jae Sung Lee*,
"Cobalt Ferrite Nanoparticles to Form Catalytic Co-Fe Alloy Carbide Phase for Selective CO_2 Hydrogenation to Light Olefins"
ACS Catalysis, 10, 8660-8671 (2020)

- Seung Ju Han, Sun-Mi Hwang, Hae-Gu Park, Chundong Zhang, Ki-Won Jun, Seok Ki Kim*,
"Identification of active sites for CO_2 hydrogenation in Fe catalysts by first-principles microkinetic modelling"
Journal of Materials Chemistry A, 8, 13014-13023 (2020)

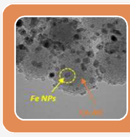
- Sun-Mi Hwang, Chundong Zhang, Seung Ju Han, Hae-Gu Park, Sunkyu Yang, Yong Tae Kim, Ki-Won Jun,* Seok Ki Kim*,
"Mesoporous carbon as an effective support for Fe catalyst for CO_2 hydrogenation to liquid hydrocarbons"
Journal of CO_2 Utilization, 37, 65-73 (2020)

- Sun-Mi Hwang, Seung Ju Han, Ji Eun Min, Hae-Gu Park, Ki-Won Jun*, Seok Ki Kim*,
"Mechanistic Insights into Cu and K promoted Fe-Catalyzed Production of Liquid Hydrocarbons via CO_2 Hydrogenation"
Journal of CO_2 Utilization, 34, 522-532 (2019)

- Chundong Zhang, Ruxing Gao, Ki-Won Jun*, Seok Ki Kim, Sun-Mi Hwang, Hae-Gu Park, Guofeng Guan,
"Direct conversion of carbon dioxide to liquid fuels and synthetic natural gas using renewable power: Techno-economic analysis"
Journal of CO_2 Utilization, 34, 293-302 (2019)

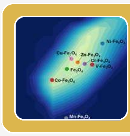


Acknowledgements



Catalyst

- Dr. Sun-Mi Hwang, *KIER*
- Ms. Ji Eun Min, *KRICT*

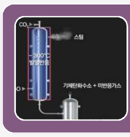


Atomic simulation

- Dr. Seung Ju Han, KRICT

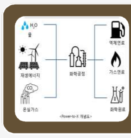
Reaction test

- Mr. Hae-Gu Park, *KRICT*



Process simulation

- Prof. Chundong Zhang, *Nanjing Tech*



Project director

- Dr. Ki-Won Jun, *KRICT*

Thank you

Questions, answers, and comments

Q. How is the robustness of direct Fischer-Tropsch (FT) compared with the conventional two-stage FT?

A. The robustness of the direct FT depends on the Fe catalyst, which has rather unstable characteristics. This needs to be overcome by adding secondary metals like Zn and Cu.

Mobile Carbon Capture (MCC)

Esam Hamad
Saudi Aramco

About the speaker:

- Senior Research Science Consultant at Aramco Services Company, USA
- PhD at University of Illinois
- Academic career as professor at Florida International University and at King Fahd University of Petroleum and Minerals

research & innovation

Mobile CO_2 Capture

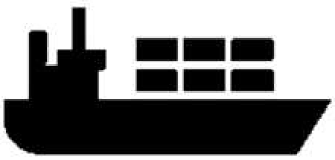
Esam Hamad
Aramco

where energy is opportunity

research & innovation

Mobile Carbon Capture Objective

Develop practical solutions for CO_2 capture from mobile sources at a reasonable cost and with minimum impact on vehicle performance



research & innovation

Mobile Carbon Capture Challenges and Opportunities

Challenges

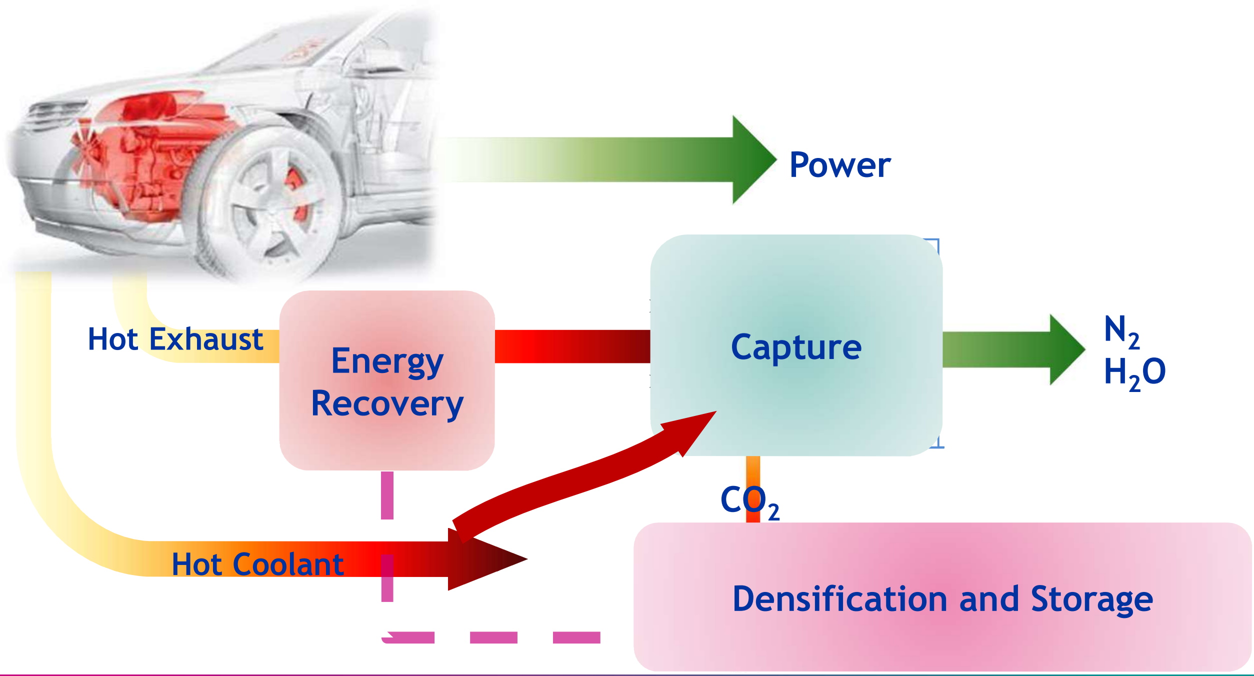
- Distributed systems (reduced economy of scale)
- Limited space
- Need for offloading infrastructure

Opportunity

- Some free energy (waste heat)
- One option to meet transportation regulations

Long term road vehicles target: 60% CO2 capture without consuming extra fuel

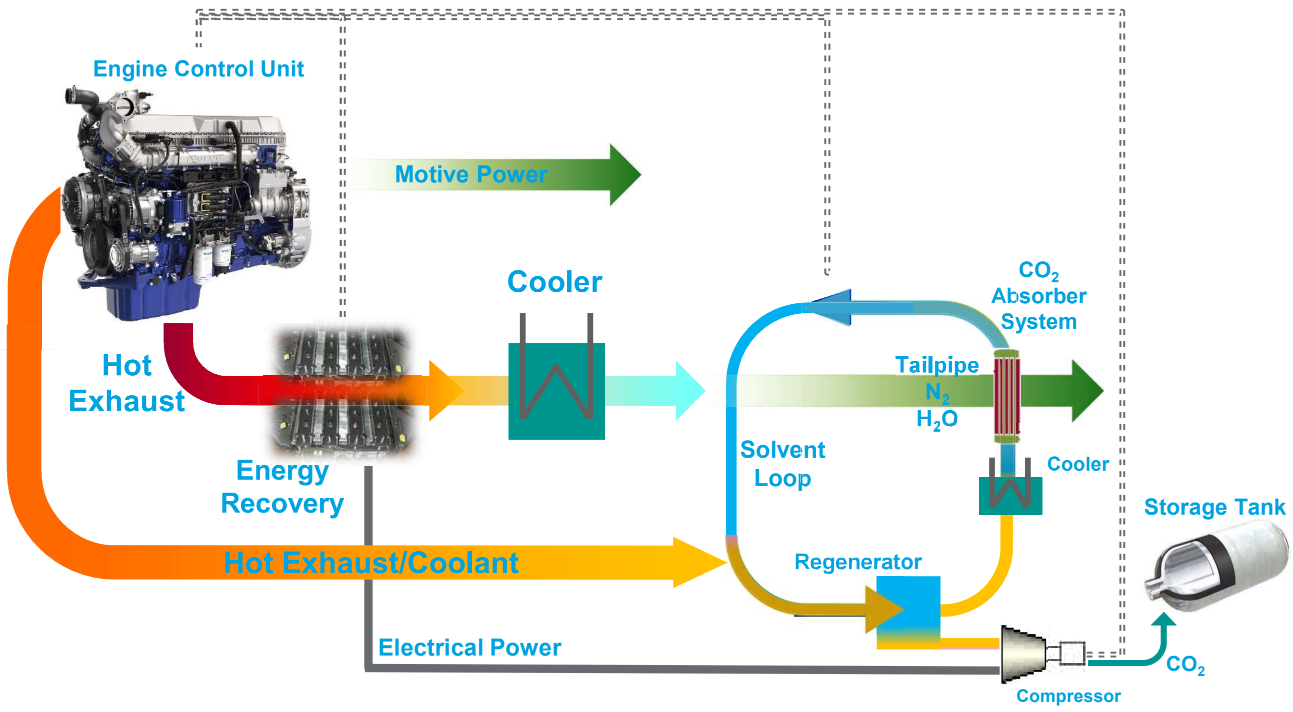
Mobile Carbon Capture (MCC): Overview



Saudi Aramco: Company General Use

aramco research & innovation

MCC System Overview

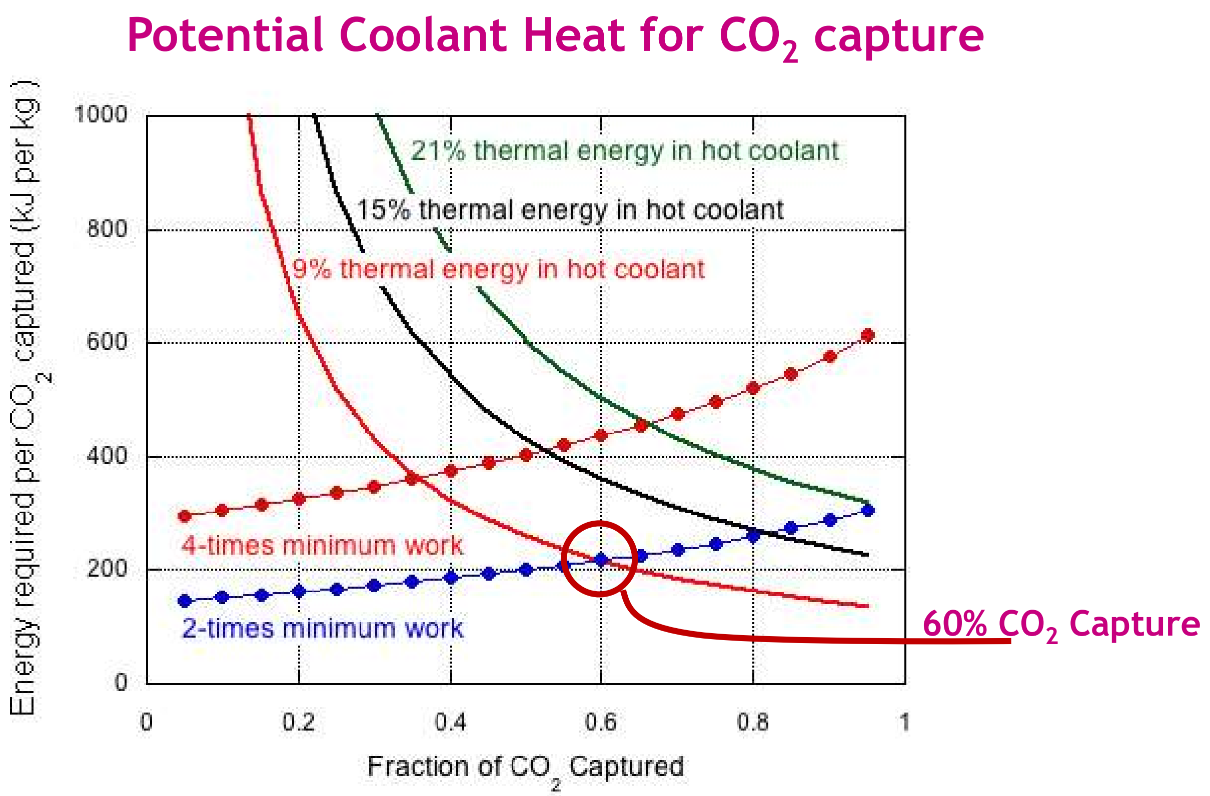


System Harvests Waste Heat for Separation and Densification

5

Saudi Aramco: Company General Use

Target: Is 60% CO2 capture achievable?



6

Saudi Aramco: Company General Use

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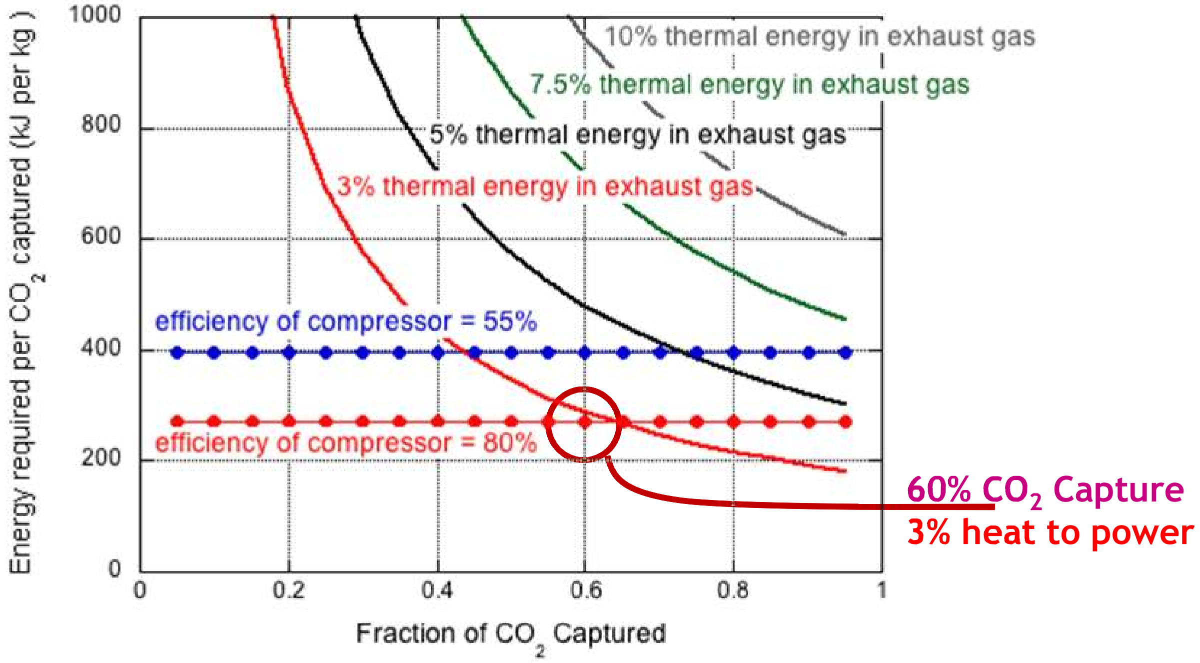
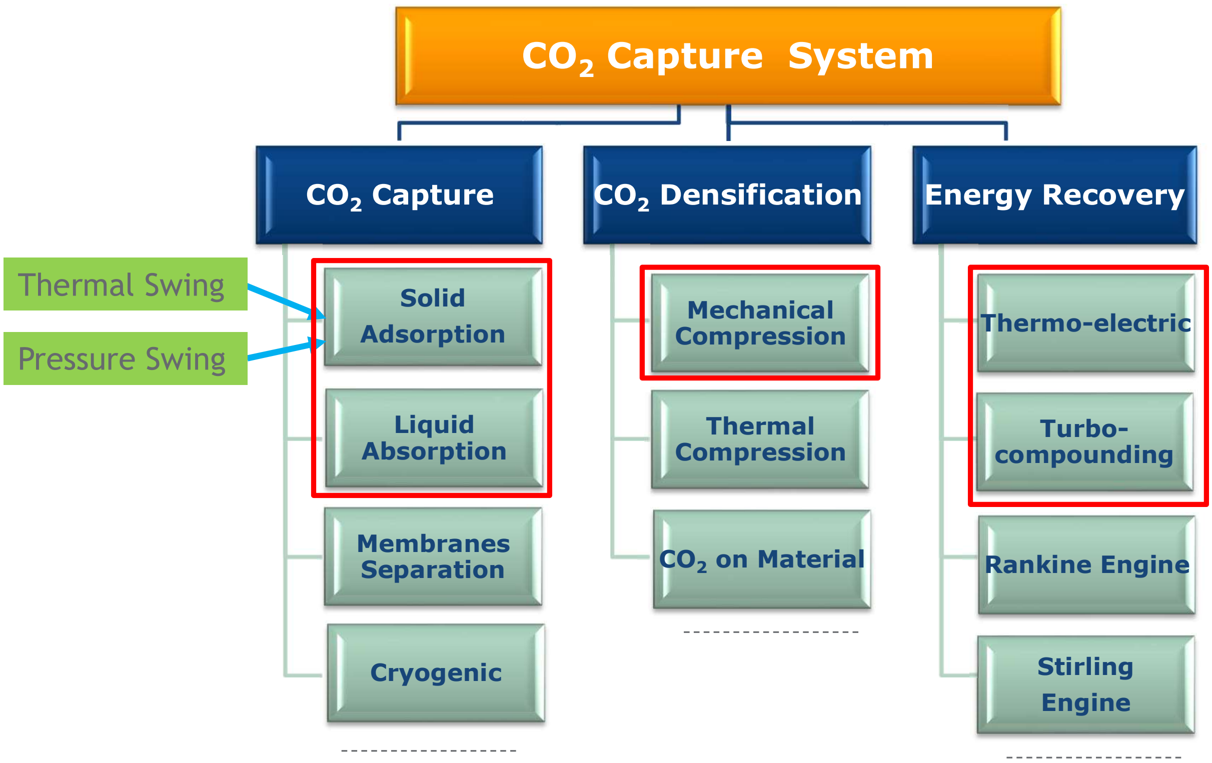
CO_2 compression energy from exhaust gas waste heat

Minimum compression work of CO_2:

218 kJ/kg of CO_2 (final pressure = 100 ATM)

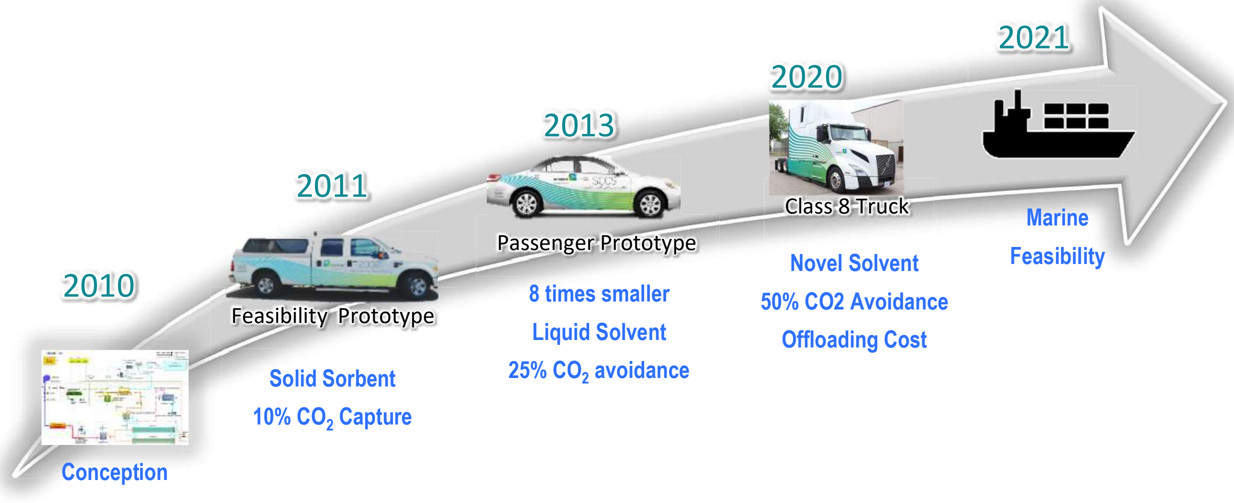


CO_2 Capture Technologies



Screen for performance, compactness and cost

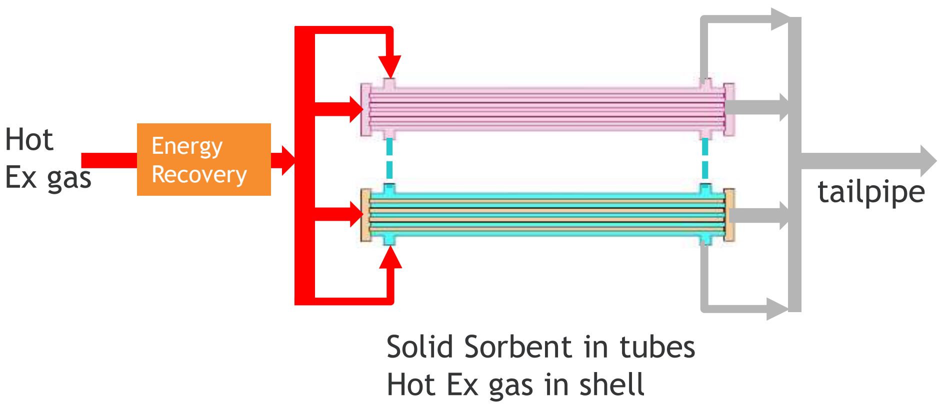
MCC Milestones



Continuous evaluation and improvement

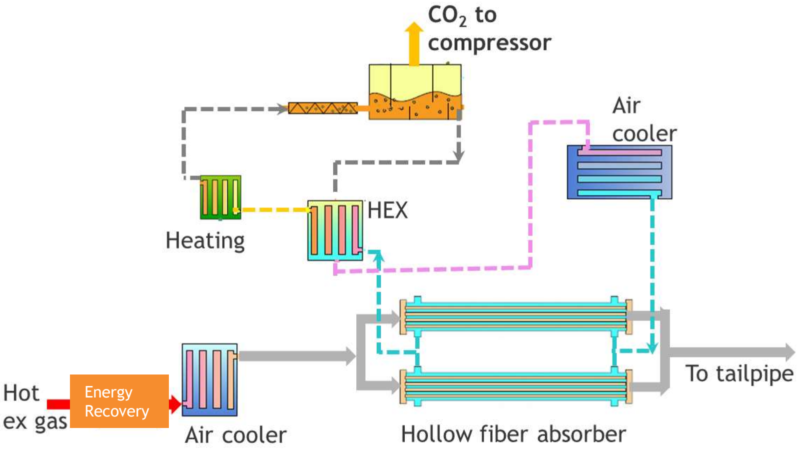
Feasibility Prototype (2011): New Solid Sorbent

- Temperature Swing Adsorption
- Showed feasibility under real driving conditions
- 10% CO2 capture
  - Developed novel high temperature sorbents: CO_2 capacity ~ 27 wt%, now 40+ wt%



Passenger Prototype (2013): Compactness & Solvent capture

- Solvent based capture
- Showed compactness (8 times size reduction)
- 25% CO_2 avoidance on drive cycle



Passenger Vehicle Prototype

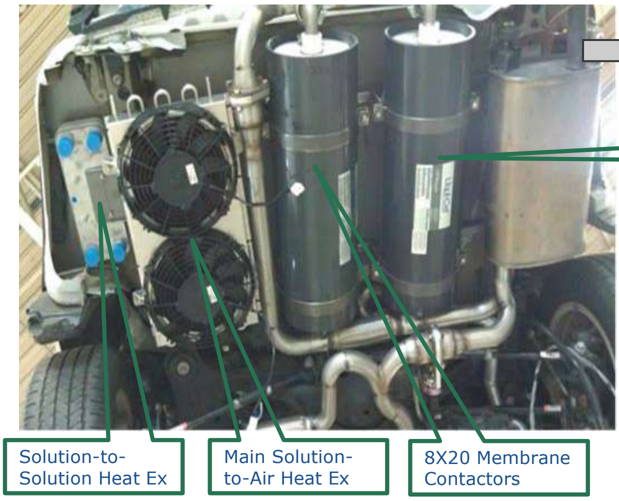
Most of the capture system underneath the car

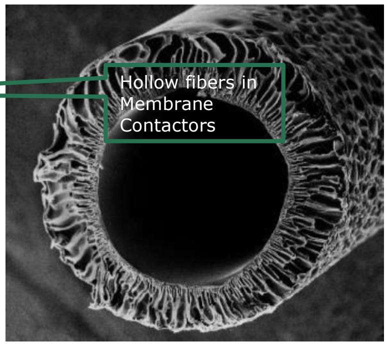
Regeneration tank close to engine under the hood

Chassis Dyno Drive Cycle Test

CO_2 storage in the trunk

Passenger Vehicle Prototype

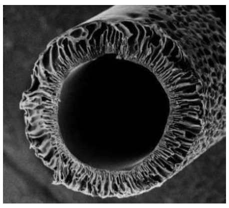




- Total contact area 53 m^2
- ID ~ 0.5 mm

Heavy Duty Vehicle (2020): Solvent capture
and Multiple energy saving technologies

CO_2 Capture: Solvent



Low Friction Lubricants

Low Rolling Resistance (single-wide)

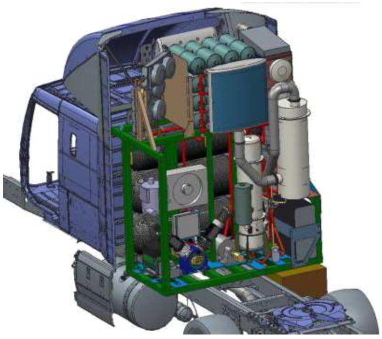
TurboCompounding

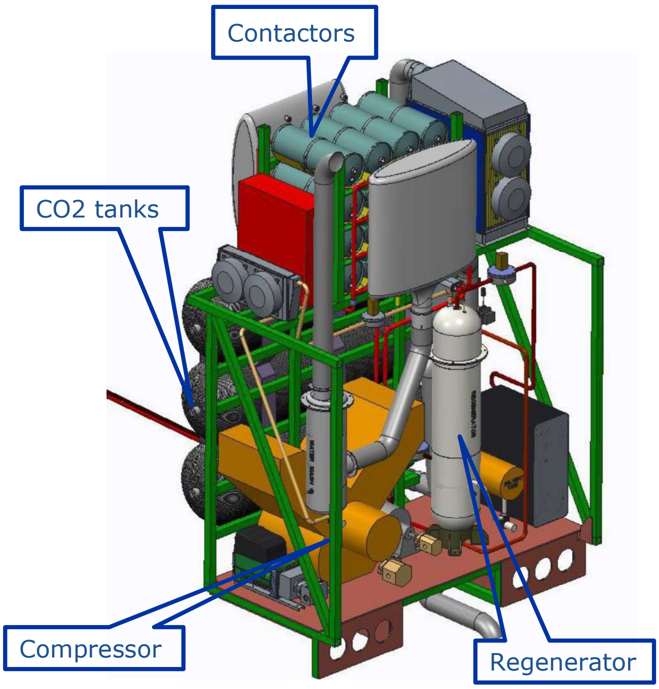
Liftable Non-Drive Axle

Aerodynamics

Heavy Duty Vehicle: Tractor-Trailer Prototype

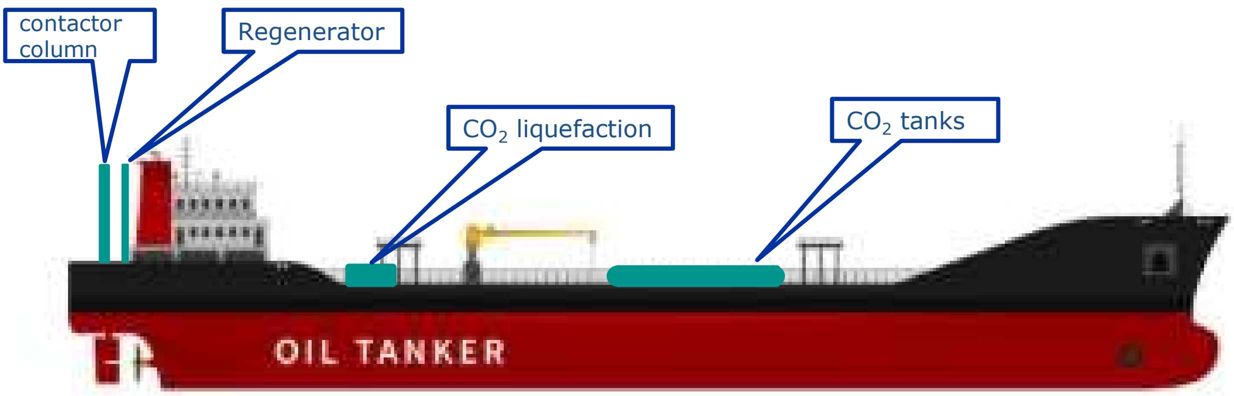
Sized for 40% capture rate with 200 gallons of fuel





Marine Carbon Capture (2021) Feasibility Study

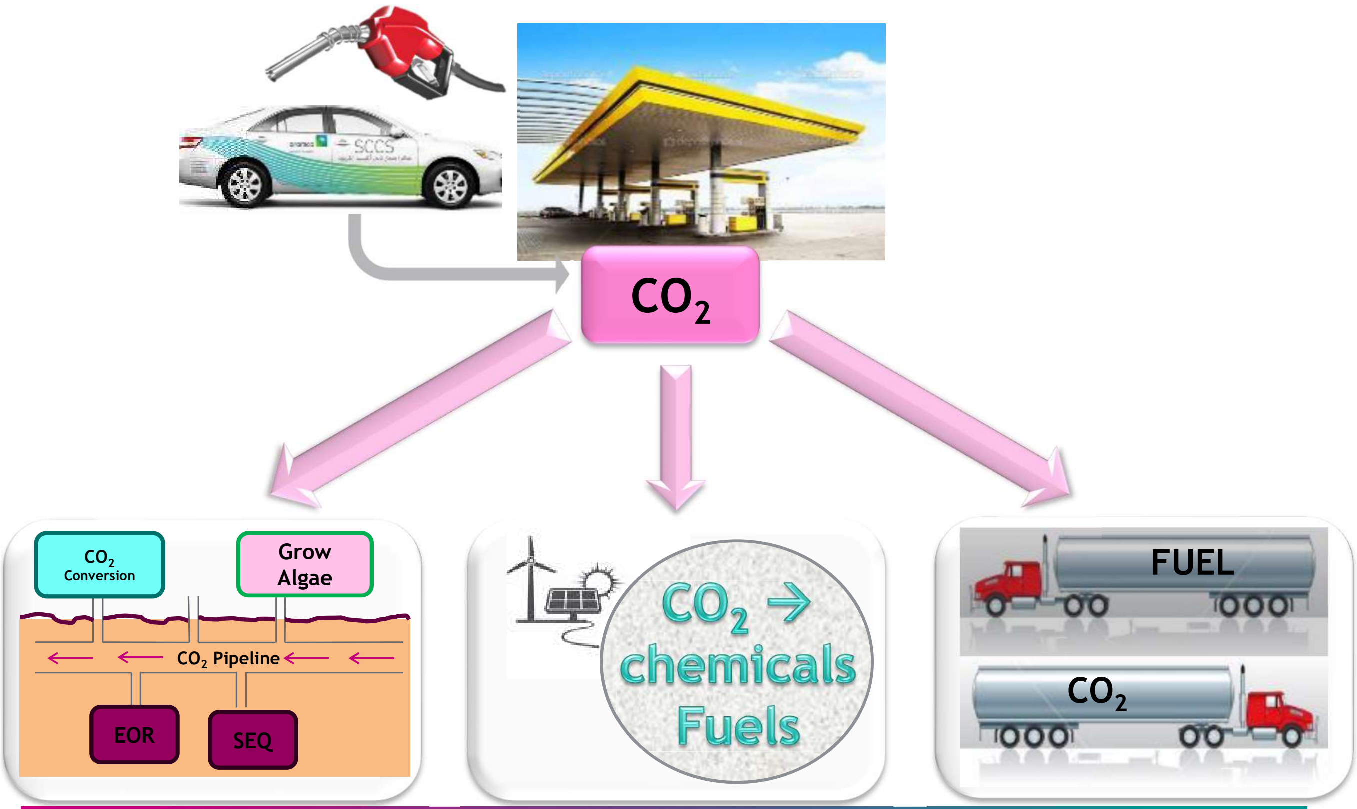
- Collaboration within OGCI (Oil and Gas Climate Initiative)
- Solvent capture selected (four technologies evaluated)
- Densification: Liquification could be an option
- **Technically feasible** but economics could be challenging for some vessels
  - Burn extra fuel for vessels that already use waste heat (economizer)



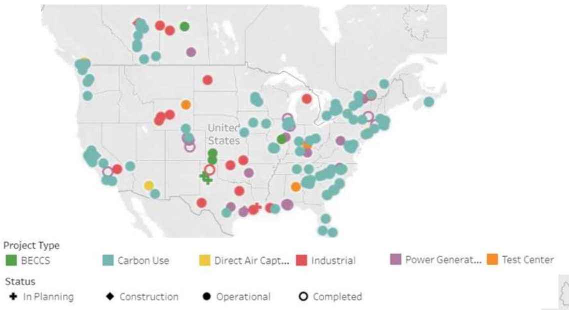
Small Scale Marine Demo: Mitsubishi, K-Line and ClassNK "CC-Ocean"

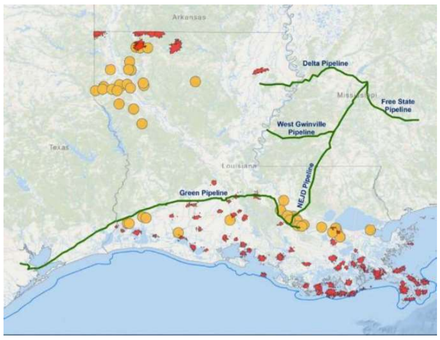
- Very small split stream in a coal carrier vessel
- Liquid solvent
- No waste heat recovery, densification or storage
- Evaluate swaying and vessel crew operation

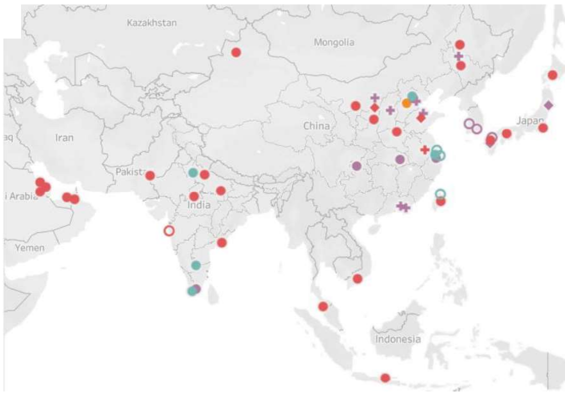
What To Do With the Captured CO2?



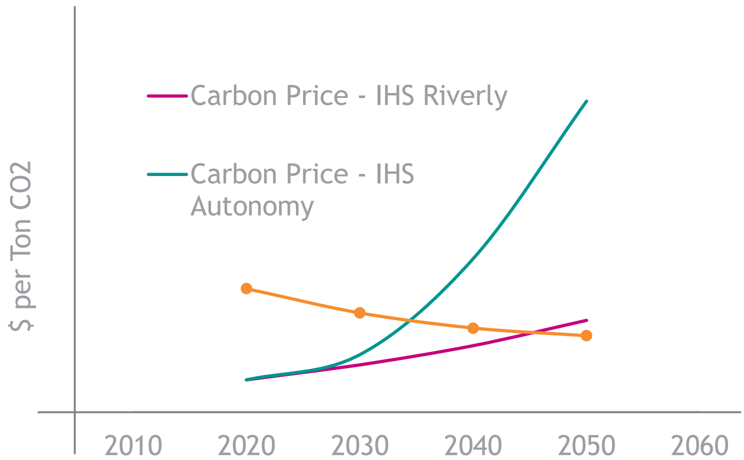
CO2 infrastructure maps







Mitigating MCC cost



MCC will be economically feasible in carbon regulated markets

Conclusions and Future Plans

Conclusions

- Mobile Carbon Capture is **technically feasible** for road vehicles and marine vessels
- Different capture technologies have their own pros and cons
  - Solvent systems have the best potential
- Commercialization will depend on **future regulations and overcoming challenges**

Future Plans

- Improve competitiveness
  - Cost
  - Compactness

Questions, answers, and comments

Q. Can you give us the feeling for semi-trucks? How heavy do you assess the complete carbon storage system you have on the truck. Do you assess it to be 1 ton or less?

A. It's a good question. So, of course, it depends on how much fuel you have. CO2 is about three times heavier than fuel. Because, you are adding 2 atoms of oxygen. In this case, you are capturing 40% of CO2 from fuel, and the fuel tank is about 200 gallons of diesel. So, initially, when you have only fuel, the way to assess them without the CO2, it is about 1 ton. A bit over 1 ton. It is not optimized for weight. Because we wanted to do some research evaluation. As the vehicles goes, you are adding directly to CO2, but, losing the weight of fuel. So you are adding to the weight a little bit. 40% times 0.3 minus 1. This is roughly how much it will be.

Q. You mentioned the solvent system in its best potential to separate CO2. But, I think there are good membranes such as Zeolite that can withstand high temperature and pressures. It is also a good candidate. I would like to know your opinion.

A. I agree. There is no method that is perfect. There are pros and cons. Zeolite as solid solvent, they have some challenges. The watcher will reduce the CO2 capacity a lot. So, you have to dry the whole exhaust gas. So, you need more equipment and energy. If we put Zeolite in membranes, you need driving force. So, you need to compress the exhaust gas or create vacuum on the other side of membrane. All these require mechanical energy. From our calculations, we have heat energy available already. Converting heat energy to mechanical energy, we lose efficiency. However, there is a challenge for low temperature. It is possible. I'm not saying it is not possible.

Q. I have a question about the phase of the stored CO2. Is it stored as liquid or compressed gas?

A. It is a supercritical fluid. If it is in cold temperature, it is typically in supercritical gas.