Energistyrelsen

Bilag: Modenhedsanalyse ud fra TRL-skalaen

Kontor/afdeling
SYS

Dato
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Modenhedsvurderingen tager udgangspunkt i IEA's ETP Clean Energy Technology Guide, november 2021.[1]

Figur 1 viser definitionen af modenhed ud fra TRL-skalaen, som angivet i IEA's ETP Clean Energy Technology Guide.

[1] IEA, ETP Clean Energy Technology Guide, november 2021 https://www.iea.org/articles/etp-clean-energy-technology-guide

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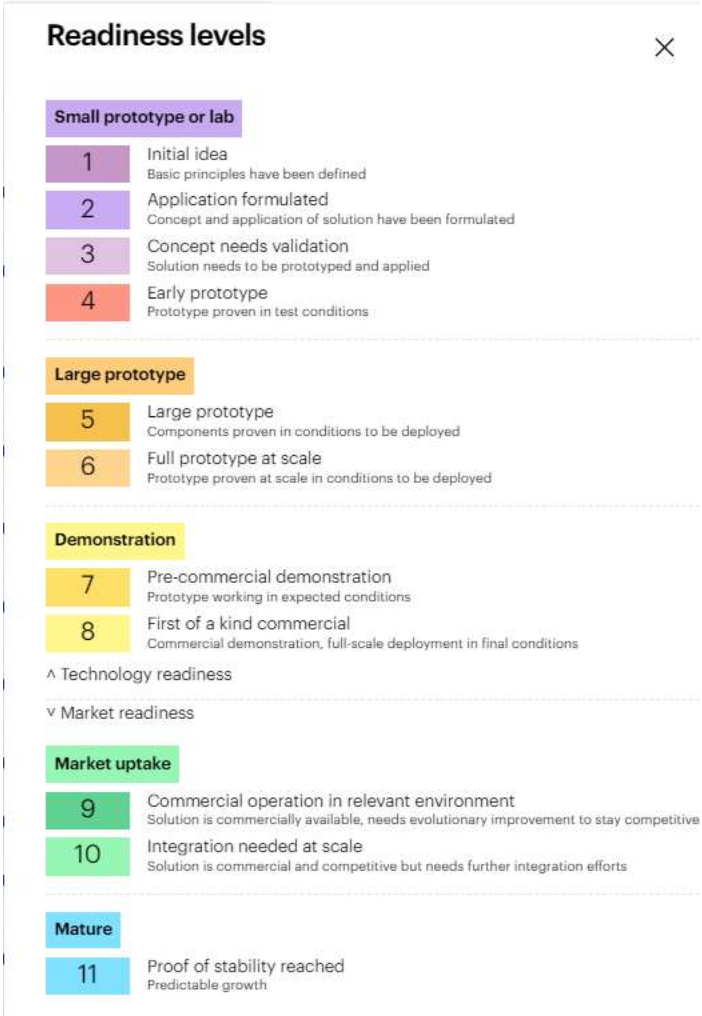
Tabel 1 viser TRL-niveauet for en række relevante teknologier for hvert omstillingselement. Den samlede modenhed ud fra TRL-skalaen som vurderet af Energistyrelsen er angivet for hvert omstillingselement.

Tabel 2 viser teknologibeskrivelsen i ETP Clean Energy Technology Guide for hver af de teknologier, der fremgår af Tabel 1.



Figur 1. Definition af TRL-niveauer for modenhedsvurdering af teknologier. Kilde: IEA, ETP Clean Energy Technology Guide, november 2021.

Tabel 1. Modenhedsvurdering for en række teknologier. Kilde: IEA, ETP Clean Energy Technology Guide, november 2021.

	Teknologi	TRL	Samlet TRL (vurderet af ENS)
Husholdninger			
Varmepumper og fjernvarme i husholdninger	Air-to-air heat pump Air-to-water heat pump Heat exchanger Heat pumps > Ground-source heat pump > Shallow	10 10 10 10	10
Energibesparelser i husholdninger	Smart meter Interval/time of use meter Control systems Air sealing Structural insulated panel Extending lifetime Natural ventilation	10 10 9 9 9 9 11	9-11
Produktion af olie, gas og VE-brændstoffer			
Elektrificering af raffinaderier	High temperature heating > Electromagnetic heating for large-scale industrial processes > Induction Low to medium temperature heating > Large-scale heat pump	10 9	9-10
Skift til bio-feedstock på raffinaderier	Biorefining Synthetic iso-parafins Gasification and hydrogen enhacement and Fischer-Tropsch Hydroprocessed esters and fatty acids Fatty acid methyl ester	7 7 5 9-10 9-10	7-10
CCS på raffinaderier [3]	Refining > Post combustion capture Refining > Oxy-fuelling capture Biomass > CCUS > Post-combustion/chemical absorption CCUS > Chemical absorption CO2 storage / Depleted oil and gas reservoir CO2 storage / Saline formation CO2 transport > Shipping > Port-to-port shipping CO2 transport /Pipeline	3-4 5 8 9 7 9 6-7 10	8-9
Elektrificering af olie- og gasindvinding i Nordsøen	Low to medium temperature heating > Large-scale heat pump High temperature heating > Electromagnetic heating for large-scale industrial processes > Induction	9 10	9-10
Metanisering af CO2 fra biogasanlæg	Methane > Methane from hydrogen and CO2	6	6
El og fjernvarme			

Biogasomlægning fra kraftvarme til opgradering	Biomethane > Anaerobic digestion and CO2 separation > without CCUS Biogas > Anaerobic digestion > Non-algae feedstock Biomethane > Biomass gasification - small-scale	8-9 9-10 9	8-10
CCS på el-, fjernvarme- og biogasanlæg [3]	Biomethane > Anaerobic digestion and CO2 separation > with CCUS Biomass > CCUS > Post-combustion/chemical absorption CCUS > Chemical absorption CO2 storage / Depleted oil and gas reservoir CO2 storage / Saline formation CO2 transport > Shipping > Port-to-port shipping CO2 transport /Pipeline	7 8 9 7 9 6-7 10	8-9
Serviceerhverv			
Varmepumper og fjernvarme i serviceerhverv	Air-to-air heat pump Air-to-water heat pump Heat exchanger Heat pumps > Ground-source heat pump > Shallow	10 10 10 10	10
Fremstillingserhverv og bygge-anlæg			
Energieffektivisering i procesenergi og intern transport [1]	Smart meter Interval/time of use meter Control systems Air sealing Structural insulated panel Extending lifetime	10 10 9 9 9 9	9-10
Elektrificering i procesenergi og intern transport [1]	Cement kiln > Electrification (direct) High temperature heating > Electromagnetic heating for large-scale industrial processes > Induction Low to medium temperature heating > Large-scale heat pump Low to medium temperature heating > Electromagnetic heating for large-scale industrial processes > Infrared Shipping/Operations > Cold Ironing (landstrøm)	4 10 9 9 9	4-10
Bio- og PtX-brændstoffer i intern transport	*Ikke beskrevet*	-	-
Gas og PtX-brændsler i direkte fyrede processer [2]	Cement kiln > Partial use of hydrogen Manufacturing > Ancillary processes > Hydrogen for high-temperature heat	4 3	3-4
CCS i fremstillingserhverv [3]	Biomass > CCUS > Post-combustion/chemical absorption CCUS > Chemical absorption CO2 storage / Depleted oil and gas reservoir	8 9 7	8-9

	CO2 storage / Saline formation	9	
	CO2 transport /Pipeline	10	
	CO2 transport > Shipping > Port-to-port shipping	6-7	
Transport			
Elektrificering og brint i vejtransport	Battery electric vehicle > Passenger car	9	8-11
	Battery electric vehicle > Light commercial vehicle	9	
	Battery electric vehicle > Urban transit bus	9	
	Battery electric vehicle > Truck	8-9	
	Battery electric vehicle > Battery > Lithium-ion	9-11	
	Hydrogen fuel cell electric vehicle > Hydrogen tank	8-9	
	Hydrogen fuel cell electric vehicle > Truck	7-8	
	Hydrogen fuel cell electric vehicle > Polymer electrolyte membrane fuel cell	9	
	Hydrogen Refuelling Station	9	
	CO2- and electrolytic hydrogen-based produced with variable renewables	8	
	Production > Electrolysis > P olymer electrolyte membrane	9	
	Production > Electrolysis > Al kaline	9	
Elektrificering og brint i søfart	Shipping/Hydrogen fuel cell electric vehicle > Solid Oxide	7	3-9
	Charging and refueling > Bunkering > Hydrogen	3	
	Shipping/Hydrogen fuel cell electric vehicle > Molten Carbonate	7	
	Shipping/Hydrogen fuel cell electric vehicle > Proton Exchange Membrane	7	
	Shipping/Battery electric vehicle	8-9	
	Shipping/ Fast charging	7	
	CO2- and electrolytic hydrogen-based produced with variable renewables	8	
	Production > Electrolysis > P olymer electrolyte membrane	9	
	Production > Electrolysis > Al kaline	9	
Bio- og PtX-brændstoffer i vejtransport	Ethanol-fuelled diesel engine	9	9
	Methanol-fuelled engine	9	
	Truck > Liquefied biogas	9	
	Truck > Compressed biogas	9	
Bio- og PtX-brændstoffer i søfart	Shipping/Ammonia-fuelled engine	4-5	8-10
	Charging and refuelling > Bunkering > Ammonia	9	
	Shipping/Methanol-fuelled engine	8-9	

	Shipping/Biogas-fuelled engine	9-10	
Bio- og PtX-brændstoffer i luftfart	*Ikke beskrevet*	-	-
Affald			
Genanvendelse og affaldsreduktion	Novel physical separation X-ray transmission Copper recycling > Extraction from cables > Ultrasonic separation New recycling techniques with reduced downcycling > Chemical depolymerization for polystyrene New recycling techniques with reduced downcycling > Pyrolysis New recycling techniques with reduced downcycling > Solvent dissolution for PET	10 9 10-11 9 9 7	7-11
CCS på affaldsforbrændingsanlæg	Biomass > CCUS > Post-combustion/chemical absorption CCUS > Chemical absorption CO2 storage / Depleted oil and gas reservoir CO2 storage / Saline formation CO2 transport > Shipping > Port-to-port shipping CO2 transport /Pipeline	8 9 7 9 6-7 10	8-9
Landbrug, gartneri, skove og fiskeri			
Fodertilsætningsstoffer	*Ikke beskrevet*	-	-
Håndtering af gylle og gødning	*Ikke beskrevet*	-	-
Udtag af lavbundsjord	*Ikke beskrevet*	-	-
Fordobling af det økologiske areal	*Ikke beskrevet*	-	-
Brun bioraffinering som for eksempel pyrolyse	*Ikke beskrevet*	-	-
Dyrkning af plantebaserede fødevarer og planteprotein	*Ikke beskrevet*	-	-
Yderligere skovinitiativer	*Ikke beskrevet*	-	-
Energieffektiviseringer i procesenergi og intern transport i landbruget [1]	Smart meter Interval/time of use meter Control systems Air sealing Structural insulated panel Extending lifetime	10 10 9 9 9 9	9-10
Elektrificering i procesenergi og intern transport i landbruget [1]	Shipping/Operations > Cold Ironing (landstrøm) High temperature heating > Electromagnetic heating for large-scale industrial processes > Induction Low to medium temperature heating > Large-scale heat pump Low to medium temperature heating > Electromagnetic heating for large-scale industrial processes > Infrared	9 10 9 9	9-10
Bio- og PtX-brændstoffer i intern transport i landbruget	*Ikke beskrevet*	-	-

Andet			
Regneeksempel for DAC (baseret på 1 GW havvind) [3]	Liquid DAC (L-DAC)	6	6
	Solid DAC (S-DAC)	6	
	CO2 storage / Depleted oil and gas reservoir	7	
	CO2 storage / Saline formation	9	
	CO2 transport /Pipeline	10	

Anm 1. NB intern transport indgår ikke i IEA's rapport

Anm 2. NB konvertering til gas indgår ikke i IEA's rapport

Anm 3: Modenhed styret af modenhed for fangst

Tabel 2. Teknologibeskrivelser. Kilde: IEA, ETP Clean Energy Technology Guide, november 2021.

Husholdninger

Varmepumper/fjernvarme i husholdninger

10	Buildings > **Heating and cooling**	Generation > Heat pumps > Air-to-air heat pump > State-of-the-art air-to-air technology	Generation	Very high	Hide

Transfer heat energy from a colder space to a warmer one, providing either heating or cooling (using either outdoor air or indoor air as a source of heat) thanks to vapor compression refrigeration and a refrigerant system. Typically more efficient than electrical resistance heaters, although efficiencies begin dropping significantly with low outside air temperature (below 5°C).

Cross-cutting themes: Direct electrification

Key countries: Europe, China, Japan, United States

Key initiatives:

- Heat Pump Technology Coolaboration Program, Source

10	Buildings > **Heating and cooling**	Generation > Heat pumps > Air-to-water heat pump > State-of-the-art air-to-air technology	Generation	Very high	Hide

Heat pump transferring heat from the outside air to a water-based system, to provide either hot water or to be used for space heating.

Cross-cutting themes: Direct electrification

Key countries: Europe, China, Japan, United States

Key initiatives:

- Heat Pump Technology Coolaboration Program, Source
- BEIS, Electrification of Heat Demonstration Project, Source

Announced cost reduction targets:

- Reduction of installation costs along with reduction of noise by regulation

10	Buildings > Heating and cooling	**Distribution** > Heat exchanger	Distribution	High	Hide

Advanced heat exchangers for building level substations

Cross-cutting themes: District energy

Key countries: United States, United Kingdom, Italy, Norway, Canada, France, Finland, Sweden, Germany, Netherlands

Key initiatives:

- REMOURBAN Project (Regeneration Model for accellerating the smart URBAN transformation)
- Danfoss

10	Buildings > Heating and cooling	Generation > Heat pumps > Ground-source heat pump > Shallow	Generation	High	Hide

Heat pump transferring heat to or from the ground to provide cooling or heating, thanks to a ground heat exchanger buried in the ground. More energy-efficient than air-source heat pumps, especially in winter as the underground temperature does not drop as much as other heat sources like the air or water.

Cross-cutting themes: **Direct electrification**

Key countries: Europe, China, Japan, United States

Key initiatives:

- Large scale field trials in the UK, Germany, Switzerland, Netherlands and Sweden that have helped optimise design and operation

Energibesparelser i husholdninger

10	Buildings > Systems integration	Demand response > Smart meter	Demand response	High	Hide

Smart meters are electronic devices that record electricity consumption on a hourly basis or more frequently, and report at least daily to utilities. Smart meters are capable of two-way communication, sending time-based pricing information toward the home or demand reponse commands to devices.

Cross-cutting themes: Systems integration, **Digitalization**

Key countries: United States

Key initiatives:

- Smart meter deployment is advanced in several countries
- Almost full deployment in China
- Over half of the market in the US and in the EU

10	Buildings > Systems integration	Demand response > Interval/Time of use meter	Demand response	High	Hide

Switch connected to an electricity meter turning on in periods of off-peak tariffs (under a time-of-use (TOU) pricing scheme)

Cross-cutting themes: Systems integration, **Digitalization**

Key countries: France, United Kingdom

Key initiatives:

- In France, 13 million of electric water heaters with storage tanks (up to 8GW during night periods in winter) are switched on/off according to a predefined schedule. 175hz PLC control signals are sent through the distribution grid.
- In Great Britain, the vast majority of customers with storage heaters (1.7m) are on ToU tariffs such as Economy 7 and have their meter controlled by radio teleswitch devices. Over 1.3m of them are on 'static' switching schedules, but around 200,000 meters are 'dynamically' controlled, with switching schedules changing on a daily basis In both cases, smart meters are expected to take over in the future. Some other countries (US, New Zealand, etc) also have other load management schemes, sometimes incentive-based.

9	Buildings > **Heating and cooling**	Control systems	Control systems	Moderate	Hide

Programmable thermostat allowing full control schedules for HVAC operation, based on your the user's preferences of climate control. A smart thermostat goes far beyond relying on a simple schedule that traditional thermostats might rely on, and can include self learning algorithms, predictive building controls, occupant level controls, thermal zoning.

Cross-cutting themes: Digitalization

Key countries:

9	Buildings > **Buildings construction and renovation**	Thermal performance > Building envelope > Wall, roof & façade > Air sealing	Thermal performance	Very high	Hide

Systematic sealing of air leakages throughout the building surface (and particularly around cracks, small holes, plumbing, wiring, lighting and ductwork) to reduce heat loss and better control humidity. This needs to be coupled with appropriate ventilation. Technologies: foam, caulk, tape, or gaskets

Cross-cutting themes:

Key countries: United States

Key initiatives:

- Many rebate programs for air sealing projects : 400$ from Efficiency Maine trust, 150-300$ for residential Minnesota Xcel Energy customers, CenterPoint Energy customers in Minnesota, Puget Sound Energy customers in Washington. Also products for DIY air sealing

Announced cost reduction targets:

- $175/yr savings according to Source

9	Buildings > **Buildings construction and renovation**	Material efficiency > Extending lifetime	Material efficiency	High	Hide

Modular building components include re-configurable systems, and overall systems, networks and designs that allow disassembly so that buildings can meet different needs (e.g. serving as a meeting room, conference room, co-working space, etc) or even be used for different functions (e.g. office space, residential use, etc)

Cross-cutting themes: Material efficiency

Key countries:

Key initiatives:

- EPA's Comprehensive Procurement Guideline (CPG) Program

Deployment targets:

- United States

Announced cost reduction targets:

- The global precast construction market size was estimated to be several dozens of million of USD.

9	Buildings > **Buildings construction and renovation**	Thermal performance > Building envelope > Wall, roof & façade > Structural Insulated Panel	Thermal performance	High	Hide

Structural insulated panels oriented-strand board or side of an insulating core

Cross-cutting themes:

Key countries:

Key initiatives:

- A list of case studies is available at this link : Source. There is no specific initiative related to structural insulated panels, but deployment is expected to increase thanks to regulation and energy efficiency incentives.

Announced cost reduction targets:

- Today's cost for structural insulated panels is between $45 to $75 per panel

11	Buildings > **Buildings construction and renovation**	Thermal performance > Ventilation > Natural ventilation	Thermal performance	Very high	Hide

Supplying air to while removing air from an indoor space without the support of a mechanical system, but exploiting pressure differences between inside and outside the building

Cross-cutting themes:

Key countries:

Key initiatives:

- International Centre for Indoor Environment and Energy (ICIEE) Danish Technical University (DTU), Denmark, Source
- Indoor Environmental Quality Lab, the University of Sydney, Source

Produktion af olie, gas og VE-brændstoffer

Elektrificering af raffinaderier

9	**Industry** > Cross > cutting	Production > Low to medium temperature heating > Large-scale heat pump	Production	Very high	Hide

Large, industrial sized heat pumps can use renewable energy from air, water or ground but also waste energy from buildings and processes to provide heating and cooling. Heat pumps are considered large if they exceed capacities of 100 kW. Current technology can easily reach the one to several megawatt range with the largest units providing 35 MW in a single machine.

Cross-cutting themes: Renewable heat, District energy, Direct electrification

Key countries: Denmark, Sweden, Germany, Norway

Key initiatives:

- Skjern has a total capacity of 5,2 MW, and achieves a plant COP between 6,5 and 7
- Seawater is used in the first DHC project using an ultra-low GWP refrigerant, in a heat pump of 16 MW and a COP of 4.4
- Nagold heating and cooling system is highly innovative, providing 100% of building heating and cooling demands by regenerative energy source through a 101 kW heat pump

Deployment targets:

- Deployment: 25% share in DH by 2050 (Heat Roadmap Europe)

Announced cost reduction targets:

- Performance: Targets focus on perfomance of components

9	**Industry** > Cross > cutting	Production > Low to medium temperature heating > Electromagnetic heating for large-scale industrial processes > Infrared	Production	High	Hide

Infrared radiation transmits heat through electromagnetic waves, heating objects directly, without the need to first heat the air in order to transmit heat to a product. It means higher heat transfer rates and faster time response, producing zero on-site emissions. Electric infrared radiation (IR) ovens offer an efficient and cost-effective alternative to convection ovens. In addition, they can provide fine control of IR wavelength in order to match specific requirements of an application. While already commercial for some applications, research and development could expand the range of applications, further improve efficiency and reduce costs.

Cross-cutting themes: Direct electrification

Key countries: United States

Deployment targets:

- A pipe fitting plant located in Anniston, Al, with the support from Alabama Power, recently introduced electric infrared heating at their facility to dry products after the painting process. They replaced a gas-fired convection oven that was causing several stops to the production lines (due to maintainance of gas filters and emissions), and saw significant productivity increase as well as reduction in maintenance. The estimated payback time is less than 1 year.

Skift til bio-feedstock på raffinaderier

7	Energy transformation > **Biofuels**	Production > Biorefining	Production	High	Hide

Similar to petroleum refineries, but solely using biomass resources. A biorefinery is an integrated system that converts a variety of biomass resources via several biofuel production processes into multiple biofuels and bioproducts.

Cross-cutting themes: Bioenergy

Key countries:

Key initiatives:

- The Crescentino Biorefinery in Italy is a demonstration plant that produces 40,000 tonnes of lignocellulosic bioethanol per year, and includes a 13 MW lignin boiler for green electricity production and biogas production from an on-site wastewater treatment facility.
- Total recently completed the conversion of La Méde petroleum refinery into a biorefinery, producing HVO/HEFA biodiesel and biojet and plans to produce Avgas (fossil fuel aviation gasoline) and AdBlue (additive for road diesel engines that reudce nitrogen oxide emissions), showcaing biofuel and well as fossil fuel products.
- World Energy/AltAir converted biorefinery in Paramount California signed a deal with Amazon in May 2020 to provide up to 6 million gallons of biofuel. Source
- Aemetis, a United States company, is expanding its current scope of ethanol production to include biogas upgrading to biomethane, production of HVO diesel and HEFA biojet fuel using biomass-based hydrogen, and carbon capture and storage at both of its in California. The new site will be operation around 2024.

Announced cost reduction targets:

- The US DOE has set a target of $3/gallon gasoline equivalent (GGS) in 2022 and $2.50/GGE by 2030 for an integrated biorefinery approach to produce hydocarbons from lignocellulosic ethanol and lignin

7	Energy transformation > **Biofuels**	Production > Biodiesel and biokerosene > Synthetic Iso-Paraffins	Production	High	Hide

Also known as the "sugars to hydrocarbons" route, this pathway converts sugars from biomass directly into hydrocarbons similar to diesel and jet fuel. Biological routes use micro-organisms to perform the conversion, while catalytic routes use catalysts under high temperature conditions.

Cross-cutting themes: Bioenergy

Key countries: United States, France

Key initiatives:

- Amyris, an industrial biosciences company based in the United States, teamed up with Total to produce farnesene (a sugar-to-hydrocarbon) that can be blended up to 10% with fossil jet kerosene. Airbus and Cathay Pacific signed a two-year offtake agreement with Amyris and Total from 2016 to 2018. In 2016, Amyris, Total and Renmatix won a 3 year contract with the US Department of Energy to develop an integrated cellulosic sugar-to-farnesene process.

Announced cost reduction targets:

- Amyris, Renmatix and Total set a production cost target of 2 USD/L for the 3-year contract with the US DOE

5	Energy transformation > **Biofuels**	Production > Biodiesel and biokerosene > Gasification and hydrogen enhancement and Fischer-Tropsch	Production	High	Hide

The biomass-based Fischer Tropsch pathway (bio-FT) is typically referred to as a biomass-to-liquid (BTL) route, though this umbrella term can apply to any route which produces liquid fuel from biomass. In the bio-FT route with hydrogen enhancement, biomass is first gasified into syngas (mostly hydrogen, carbon monoxide and carbon dioxide). Instead of sending the syngas to a water-gas shift (WGS) reactor, as is done in the usual bio-FT route, low-carbon hydrogen is added to the syngas to drive a reverse water-gas shift (rWGS) reaction, converting hydrogen (H2) and carbon dioxide (CO2) into water and carbon monoxide (CO). Sufficient hydrogen is added to ensure a desired H2/CO ratio for Fischer-Tropsch (FT) synthesis. The liquids from the FT reactor are further cleaned and separated into their drop-in hydrocarbon products (diesel, jet, naptha, etc). The benefit of adding hydrogen is a more efficient use of the carbon in biomass, as the carbon in CO2 is converted into hydrocarbon fuels rather than being either vented (bio-FT route) or captured and stored (bio-FT w/ CCS route). Rather than providing negative emissions, the additionally converted carbon can displace fossil carbon within the energy system. Technical challenges revolve around tar buildup and removal during gasification.

Cross-cutting themes: Bioenergy

Key countries: European Union

Key initiatives:

- In 2021, the project FLEXCHX in the European Union (funded by the EU Horizon 2020 programme) successfully met its objectives to demonstrate a flexible production of power and heat using an hydrogen-enhanced biomass gasification with Fischer-Tropsch system. A variety of companies across the entire value chain took part. A solar plant was used to power a water electrolyzer for hydrogen production during the summer months to maximize FT-syncrude that could be sent for upgrading at a refinery. The success of the project has elevated the TRL of this route to 5.

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9-10	Energy transformation > **Biofuels**	Production > Biodiesel and biokerosene > Hydrogenated vegetable oil / Hydroprocessed esters and fatty acids	Production	Moderate	Hide

Hydrogenated vegetable oil (HVO) - also known as hydroprocessed esters and fatty acids (HEFA) - is a type of renewable diesel while HEFA is a type of drop-in biokerosene, meaning it is a drop-in fuel and theoretically has no upper blend limit with fossil diesel and kerosene, though it is currently capped at 50% blend for use in aviation. HVO is produced via well-known hydrotreatment commonly used at petroleum refineries. An oil feedstock (vegetable oil such a soybean, palm or rapeseed, or waste oils such as animal fats and used cooking oils) is reacted with hydrogen in the presence of a catalyst to remove oxygen and break the triglycerides in the oil into three separate hydrocarbon chains. When compared to FAME biodiesel, HVO/HEFA has better storage stability, cold flow properties and higher cetane number (higher ignitibility).

Cross-cutting themes: Bioenergy

Key countries: Finland, Singapore, United States, France, Italy, Netherlands, China

Key initiatives:

- As a relatively new but enthusiastically expanding industry, there are a variety commercially operating dedicated new builds and refinery conversions and co-processing HVO/HEFA plants globally with a cumulative production capcaity of 8 million tonnes/year (10.3 billion L/yr)
- The first HVO plant operator and current global capacity leader is Neste, responsible for 3.2 million tonnes per year across its four sites (Finland, Singapore and Netherlands), with a 1.3 million tonnes per year extension currently under development in Singapore. Neste's feedstock now consists of over 80% waste oils such as used cooking oil (UCO), animal and fish fats, and residues from vegetable oil refining.
- In France, Total recently started operations (2019) in a refinery converted to HVO/HEFA biodiesel and biojet production, at a capacity of 0.5 million tonnes per year.
- Italy, Eni similarly has recently (2019) begun operation of a converted refinery with a production capacity of 0.75 million tonnes per year, with the ability to use waste oils and residues.
- In the United States, Diamond Green Diesel (Louisiana) has the largest production capacity at 800,000 tonnes per year, while World Energy's AltAir facility (California) has a 125,000 tonne total capacity, and is the only facility in the world continuously producing HVO/HEFA jet fuel. Renewable Energy Group recently cancelled a 250,000 tonne/yr plant that had been planned for Washington state.
- China has a total HVO production capacity of 220,000 tonnes/yr split between two sites, SINOPEC and ECO/Yangzou Jianuyan/Huanyu.
- In the Netherlands (Sept 2021), Shell reached a final invesment decision to convert an existing petroleum refinery into a biorefinery that can will produce 820 kilotonnes per year of renewable diesel and biokerosene in 2024. The facility will use both waste oils and sustainable vegetable oils. It has ambitions to produce 2 million tonnes/yr by 2025.

Deployment targets:

- Since 2020, numerous airlines, fuel suppliers, and airports have pledged to be net zero by 2050 or earlier in some cases, with sustinable aviation fuels (SAF) like HEFA/HVO playing a leading role. Several SAF blending mandates are under consideration across Europe, which a targer of 0.5% SAF already adopted by Norway. The ReFuelEU Aviation initiative in the EU proposes blending obligations at EU airports, starting with 2% SAF in 2025 and rising to 63% by 2050. Additionally, the US has launched its Sustainable Aviation Fuel Grand Challenge, targeting 3 billion gallons of SAF per year by 2030, and 35 billion gallons by 2050. The International Civil Aviation Organization (ICAO) has set a goal for carbon-neutral growth from 2020 onwards, and has adopted the Carbon Offsetting and reduction for International Aviation (CORSIA) framework, which include SAF as an option for carbon emissions reduction. HVO/HEFA kerosene/jet fuel is an American Society for Testing and Materials (ASTM)-certified SAF pathway.

9-10	Energy transformation > **Biofuels**	Production > Biodiesel and biokerosene > Fatty acid methyl ester	Production	Moderate	Hide

Fatty acid methyl ester (FAME) biodiesel is produced by reacting either vegetable oil (soybean, palm, rapeseed) or waste oils (animal fats, used cooking oils) with methanol in the presence of a catalyst. The transesterification reaction of the triglycerides found within the oils produces biodiesel and glycerine. The biodiesel and glycerine undergo a series of purification and separation steps to clean the final products and to recover the catalyst and any remaining methanol. Glycerine can be sold to the pharmaceutical industry. The biodiesel can be blended up to 5-7% with fossil diesel for use in road transport, or can be blended up to 100% for use in marine diesel engines.

Cross-cutting themes: Bioenergy

Key countries: Europe, Indonesia, United States, Brazil, Germany, Argentina, France

Key initiatives:

- FAME biodiesel is produced at a commercial scale across the world. In 2019, a total of 38.5 million tonnes of FAME were produced. Four countries dominate in FAME production, contributing to 55% of global production. This includes Indonesia (18.2%), United States (15.6%), Brazil (12.5%) and Germany (8.8%). As a region, Europe is the largest producer, accounting for 33.3% of global FAME production.

Deployment targets:

- Indonesia recently increased their blending targets from 20% to 30%, with the aim of increasing to 40% blending no later than mid-2021
- India's National Biofuel Policy 2018 sets a target of 5% blending by 2039 for biodiesel.

CCS på raffinaderier

3-4	Energy transformation > **Refining**	Production > Fluid catalytic cracker > CCUS > Post-combustion capture	Production	Moderate	Hide

The fluid catalytic cracking (FCC) unit is responsible for 20-55% of total CO2 emissions from a typical refinery. Post-combustion technology to capture the CO2 from the flue gas,with a volumetric CO2 concentration of 10-20% is available, but has not yet been demonstrated in a refinery context.

Cross-cutting themes: CCUS

Key countries: Norway

5	Energy transformation > **Refining**	Production > Fluid catalytic cracker > CCUS > Oxy-fuelling capture	Production	Moderate	Hide

The fluid catalytic cracking (FCC) unit is responsible for 20-55% of total CO2 emissions from a typical refinery. CO2 concentration in the flue gas is around 8-20% (volumetric). Oxy-combustion enables the concentration and capture of CO2 in the flue gas from FCC units.

Cross-cutting themes: CCUS

Key countries: Brazil, Norway

Key initiatives:

- A pilot scale demonstration of the oxy-FCC process was performed at a Petrobas refinery in the CO2 Capture Project. The test showed that it is technically feasible to operate an oxy-FCC unit.

7	**CO2 infrastructure** > CO2 storage	Depleted oil and gas reservoir	Depleted oil and gas reservoir	High	Hide

CO2 storage involves permanent retention of CO2 in underground geological reservoirs (> 800 meter deep). The main types of geological reservoirs suitable for CO2 storage are deep saline formations and depleted oil and gas reservoirs.

Cross-cutting themes: CCUS

Key countries: United States, Canada, Norway, China, Australia, Saudi Arabia, UAE, Brazil

Key initiatives:

- Full-scale demonstration has been implemented, as part of the Regional Carbon Sequestration Partnership in the United States, as part of an initiative to stimulate regional CO2 storage.
- Examples include the In Salah project in Algeria.

Announced cost reduction targets:

- No cost reduction targets have been identified

10	**CO2 infrastructure** > CO2 transport	Pipeline	Pipeline	Very high	Hide

CO2 transport connects CO2 from capture sites with geological storage locations or sites where CO2 is used. Pipelines are a cost effective way to transport large volumes of CO2. Before pipeline transport, CO2 is compressed to increase the density of the CO2, thereby making it easier and less costly to transport.

Cross-cutting themes: CCUS

Key countries: United States, Norway, Canada, Netherlands

Key initiatives:

- In North America, an extensive network of over 7,000 km of pipelines transports around 60 MtCO2 per year, primarily for enhanced oil recovery.
- Experience with CO2 pipeline transport also exists in other countries, either for CO2-EOR purposes (e.g. Brazil, Canada, China) or dedicated geological storage of CO2 (e.g. Australia, Canada, Norway), but on a smaller scale.
- The Alberta Carbon Trunk Line provides a model for constructing oversized pipeline infrastructure to account for future needs. That pipeline has a capacity of 14.6 Mt/year even though only a fraction of that capacity is currently needed.
- The Acorn Project, United Kingdom aims to reuse 420 km offshore pipeline to connect St. Fergus with an offshore storage site.

Deployment targets:

- Several projects around the world involve development of CO2 clusters and hubs in which CO2 transport infrastructure could be shared.
- In its ACCA21 Roadmap, the Chinese Ministry of Science and Technology targets having a pipeline tranportation capacity of 20 Mtonnes/year of CO2 with a total length in excess of 2 000 km. By 2050, those targets increase to 1 Gtonne/year capacity and a total length of more than 20 000 km.

Announced cost reduction targets:

- No cost reduction targets have been identified

9	**CO2 infrastructure** > CO2 storage	Saline formation	Saline formation	Very high	Hide

CO2 storage involves permanent retention of CO2 in underground geological reservoirs (> 800 meters deep). The main types of geological reservoirs suitable for CO2 storage are deep saline formations and depleted oil and gas reservoirs.

Cross-cutting themes: CCUS

Key countries: United States, Canada, Norway, China, Australia, Saudi Arabia, UAE, Brazil

Key initiatives:

- Saline formations have been used for CO2 storage at commercial scale in a number of CCUS projects (Sleipner, Snøhvit, Quest). The following projects exemplify the ambition of leading players to develop much larger (5 to 50 MtCO2/yr) storage operations:
- The Northern Lights project involves an offshore saline storage site beneath the Northern North Sea. The project involves two phases: for phase 1 a storage rate of up to 1.5 MtCO2/year is planned; during phase 2 the storage rate will rise up to 5 MtCO2/yr.
- The CarbonNet project is developing a deep saline CO2 storage site within the Gippsland Basin in Victoria, Australia, with a capacity of 125 MtCO2. A hub-based network centred on a large capacity pipeline will be capable of delivering 5 MtCO2/yr.
- The CarbonSAFE is a United States initiative focused on development of geological storage sites with CO2 capacities of over 50 MtCO2 across the continental US. The development CarbonSAFE is expected to lead to injection by 2026.

Announced cost reduction targets:

- No cost reduction targets have been identified

Elektrificering af olie- og gasindvinding i Nordsøen

9	**Industry** > Cross > cutting	Production > Low to medium temperature heating > Large-scale heat pump	Production	Very high	Hide

Large, industrial sized heat pumps can use renewable energy from air, water or ground but also waste energy from buildings and processes to provide heating and cooling. Heat pumps are considered large if they exceed capacities of 100 kW. Current technology can easily reach the one to several megawatt range with the largest units providing 35 MW in a single machine.

Cross-cutting themes: Renewable heat, District energy, Direct electrification

Key countries: Denmark, Sweden, Germany, Norway

Key initiatives:

- Skjern has a total capacity of 5,2 MW, and achieves a plant COP between 6,5 and 7
- Seawater is used in the first DHC project using an ultra-low GWP refrigerant, in a heat pump of 16 MW and a COP of 4.4
- Nagold heating and cooling system is highly innovative, providing 100% of building heating and cooling demands by regenerative energy source through a 101 kW heat pump

Deployment targets:

- Deployment: 25% share in DH by 2050 (Heat Roadmap Europe)

Announced cost reduction targets:

- Performance: Targets focus on perfomance of components

9	**Industry** > Cross > cutting	Production > Low to medium temperature heating > Electromagnetic heating for large-scale industrial processes > Infrared	Production	High	Hide

Infrared radiation transmits heat through electromagnetic waves, heating objects directly, without the need to first heat the air in order to transmit heat to a product. It means higher heat transfer rates and faster time response, producing zero on-site emissions. Electric infrared radiation (IR) ovens offer an efficient and cost-effective alternative to convection ovens. In addition, they can provide fine control of IR wavelength in order to match specific requirements of an application. While already commercial for some applications, research and development could expand the range of applications, further improve efficiency and reduce costs.

Cross-cutting themes: Direct electrification

Key countries: United States

Deployment targets:

- A pipe fitting plant located in Anniston, Al, with the support from Alabama Power, recently introduced electric infrared heating at their facility to dry products after the painting process. They replaced a gas-fired convection oven that was causing several stops to the production lines (due to maintainance of gas filters and emissions), and saw significant productivity increase as well as reduction in maintenance. The estimated payback time is less than 1 year.

Metanisering af CO2 fra biogasanlæg

8	**Industry** > Chemicals and plastics	Methanol > Production > CO2- and electrolytic hydrogen-based produced with variable renewables	Methanol	High	Hide

A synthetic gas (or syngas) composed predominantly of CO and hydrogen is produced from methane. Under particular conditions, the CO and hydrogen react together to produce methanol. This process relies on hydrogen produced from water electrolysis. With waste CO2 from industrial processes, the yield of methanol is increased.

Cross-cutting themes: Materials, **Hydrogen**, Renewable electricity, Electrochemistry

Key countries: Japan, Iceland, Germany, China, Norway, Australia

Key initiatives:

- The George Olah Renewable Methanol Plant was commissioned by Carbon Recycling International in 2011 in Iceland and designed for a 4kt/yr capacity with a EUR 7.1 million investment. There are plans for scaling up this plant to 40kt/yr.
- Mitsui Chemicals has developed a pilot plant in Japan (capacity of 100 tonne per years), which began operation in 2009.
- DOW is undertaking a demonstration project to produce methanol by combining CO2 from a gas power plant with hydrogen, at a site Germany near Hamburg. The project was awarded funding by the Germany government in 2019. It is would produce 42 kt of methanol per year.
- The GreenHydroChem project (by a consortium involving Siemens, Linde, and Fraunhofer) is undertaking a demonstration project at a chemical site in Leuna, Germany. A 50 MW electrolyzer will produce hydrogen using renewable electricity, for conversion into methanol and other chemicals at local refineries. The project was awarded funding by the Germany government in 2019. Siemens is also looking into developing a large-scale wind power-to-methanol project in Patagonia, Argentina.
- Wacker and Lind received funding in March 2021 for a 20 MW electrolysis plant and a 15 kt synthesis plant for producing methanol.

Announced development targets:

- In April 2021, Ningxia Baofeng Energy began operation of a hydrogen production facility powered by 200-MW solar power plant (100 MW electrolyser capacity) in Northwest China's Ningxia Hui autonomous region. The hydrogen replace coal as a feedstock for producing methanol. The 16kt/yr of hydrogen production is enough to produce about 0.1 Mt methanol/yr.
- CRI is building its first commerical plant (0.1 Mt methanol/yr) in Henan, China, expected to be commissioned by the end of 2021. They are also planning a commercial plant (0.1 Mt methanol/yr) in Finnfjord, Norway, expected to begin operation in 2024.
- ABEL Energy is conducting a feasibility study for a large-scale electrolysis-based hydrogen and methanol facility at the Bell Bay Advanced Manufacturing Zone in Tasmania, Australia. The 100 MW electrolysis plant would produce 60-70 kt of methanol per year, with production expected to begin in 2023.

6	Energy transformation > **Synthetic hydrocarbon fuels**	Production > Methane > Methane from hydrogen and CO2	Production	Moderate	Hide

Methane can be produced by the reaction betweeen H2 and CO in the presence of a catalyst. Firstly, the CO2 is transformed into CO by catalytic or electrochemical processes, and then it reacts with H2 in the presence of a catalysts at medium temperatures and high pressures. It can also be produced directly from CO2, without a previous transformation into CO, under more extreme conditions and a different catalyst

Cross-cutting themes: Synthetic fuels, CCUS

Key countries: Germany

Key initiatives:

- Germany: Numeros demonstration projects developed since 2009, the largest one elonging to ETOGAS (6MW). Exytron has installed a first commercial system in a large apartment building in Augsburg combining a CHP system that uses the CH2 produced with the exahust CO2 of the CHP system and H2 from a PV-powered electrolyser using also electric storage Some demonstration projects, mainly in European countries

El og fjernvarme

Biogasomlægning fra kraftvarme til opgradering

8-9	Energy transformation > **Biofuels**	Production > Biomethane > Anaerobic digestion and CO2 separation > without CCUS	Production	Moderate	Hide

In an anaerobic digestor, bacteria break down to biomass without oxygen and in the process produce biogas, composed mostly of methane (50-75%) and carbon dioxide (25-45%). Biomass can be in the form of animal manure, organic portion of municipal solid waste (MSW), industrial waste such as dry distillers grain (DDG) from ethanol production, agricultural residues, and energy crops. The biogas is upgrading by removing CO2 and other impurities such as hydrogen sulphide, producing what is commonly referred to as biomethane.

Cross-cutting themes: Bioenergy

Key countries: Germany, France, Sweden, Netherlands, Denmark, United Kingdom, United States, China, Canada

Key initiatives:

- Although biogas production coupled with upgrading to biomethane is recent technology, there are still around 700 biogas upgrading plants worldwide, with rapid growth taking place in Europe. The majority are found in Europe, with Germany again taking the lead at 195 plants, followed by the UK (92), Sweden (70) and France (67), producing a total of 19.3 TWh of biomethane in 2017.
- The United States is home to 50 such plants, while China and Canada each have around 20 plants, and Japan, Korea, Brazil and India each having a handful.
- Upgraded biogas can be injected into the gas grid or used in vehicles. Technical standards for the produced biomethane are being developed in Europe under the auspices of the European Biogas Association.

Deployment targets:

- France aims to install 1000 biomethane plants (for injection into gas grid) by 2020. Between 2017 and 2018, it installed 23 new biogas upgrading plants.

9-10	Energy transformation > **Biofuels**	Production > Biogas > Anaerobic digestion > Non-algae feedstock	Production	Moderate	Hide

In an anaerobic digestor, bacteria break down to biomass without oxygen and in the process produce biogas, composed mostly of methane (50-75%) and carbon dioxide (25-45%). Biomass can be in the form of animal manure, organic portion of municipal solid waste (MSW), industrial waste such as dry distillers grain (DDG) from ethanol production, agricultural residues, and energy crops. The biogas can be burned directly, without upgrading to biomethane.

Cross-cutting themes: Bioenergy

Key countries:

Key initiatives:

- Biogas production via anaerobic digestion is a commercially deployed technology, consisting of small-scale (micro) digestors to produce biogas for cooking in rural developing areas, medium-scale digestors to produce heat and electricity (CHP), and large-scale digestors that produce electricity from biogas and upgrade biogas to biomethane, which can be injected into the gas grid.
- Globally, there are around 50 million micro-digesors, with 42 million in China producing 13 million Nm3/yr, and another 4.9 million in India producing 2 million Nm3/yr.
- In 2016, 87.5 TWh of electricity was produced from medium- to large-scale biogas systems. Germany is a leader of biogas with 10.5 GW installed, followed by France, Switzerland and the UK. In the United States, just under 1 GW of medium- to large-scale AD are installed, while India has 300 MW and Canada has 196 MW.
- Typical biogas plant capacity for electricity range between 0.5 to 2.7 MW in Europe

9	Energy transformation > **Biofuels**	Production > Biomethane > Biomass gasification - small-scale	Production	Moderate	Hide

Biomass can be thermally converted to gaseous products via gasification. Biomass with a high lignocellulosic content (e.g. wood, straw, residues from foresty and agriculture, munipal solid waste) is heated, but not combusted, in an oxygen-restricted environmental, producing a mixture of mostly hydrogen (H2) (20-30%), carbon monoxide (CO) (~20%), carbon dioxide (CO2) (~15%), and other hydrocarbons. Small-scale gasifiers (< 200 kWe) can provide fuel to create heat and electricity for remote villages. It can be replace burning biomass directly for cooking in the home, avoiding negative health impacts.

Cross-cutting themes: Bioenergy

Key countries: China, Japan, India, Thailand, Germany, Denmark, Sweden

Key initiatives:

- Myriad institutes in China are developing small-scale biomass gasification technologies, under the auspirces of the China Biomass Development Center (CBDC). Recently commercialised technologies use sawdust and rice husk as feedstock.

CCS på el-, fjernvarme- og biogasanlæg

7	Energy transformation > **Biofuels**	Production > Biomethane > Anaerobic digestion and CO2 separation > with CCUS	Production	Moderate	Hide

Similar to biomethane production from anaerobic digestion, with the addition of a a CO2 capture and compression unit integrated into the CO2 separation inherent to biogas upgrading. If the CO2 is stored, negative emissions are created that can offset hard-to-abate emissions elsewhere in the energy system. Larger digestors (> 5 MW) are suitable for carbon capture and storage (CCS) to justify the additional capital expense. See non-CCUS variant for more detail.

Cross-cutting themes: Bioenergy, CCUS, CO2 removal

Key countries: Italy

Key initiatives:

- In Italy, Tecno Project Industriale has constructed an anaerobic digestion plant with upgrading that captures the CO2 and sends it for use at a nearby industrial site.

8	Energy transformation > **Power**	Generation > Biomass > CCUS > Post-combustion/chemical absorption	Generation	High	Hide

At a biomass-fired power plant with post-combustion capture using chemical absorption, the carbon dioxide is separated from the combustion flue gas by using a chemical solvent (e.g. amine-based). The CO2 is released at high temperature and the solvent regenerated for further operation.

Cross-cutting themes: CCUS, CO2 removal

Key countries: United Kingdom, Japan

Key initiatives:

- Pilot and demonstration scale:
- Drax Power Station, UK. Four of Drax's six 660 MWe units have been converted from coal to 100% biomass, with the other two units remaining on coal. CO2 capture is being piloted at Drax, with the intention for the biomass units to operate in the future as BECCS units Source .
- Mikawa power plant, Japan: original 50-MW coal power plant with CO2 capture has been converted to 100% biomass, with plans to have carbon capture operational in 2020.

9	**Industry** > Chemicals and plastics	Methanol > Production > CCUS > Chemical absorption	Methanol	High	Hide

Chemical absorption of CO2 is a common process operation based on the reaction between CO2 and a chemical solvent (e.g. amine-based). The CO2 is released at temperatures typically in the range 120°C to 150°C and the solvent regenerated for further operation.

Cross-cutting themes: Materials, CCUS, CO2 removal

Key countries: Brazil, Bahrain

Key initiatives:

- We are not aware of projects currently use this capture technology in methanol production linked with CO2 storage - thus the technology is at TRL 5 for the full CCS chain, in contrast to TRL 9 for CCU.

Deployment targets:

- Multiple commercial coal-based methanol plants use chemical absorption as part of the production process, putting the capture technology itself at TRL 11. We are aware of two projects subsequently using the CO2, putting the CCU chain at TRL 9.
- A QPC Quimica methanol plant in Brazil has been capturing CO2 since 1997 using amine-base capture. Food-grade CO2 is supplied to local soft drink manufacturers.
- At a methanol plant in Bahrain, owned by Gulf Petrochemicals Industries Company, a CO2 capture project began in 2007, using the Mitsubishi KS-1 amine-based solvent. The CO2 is used to enhance methanol and urea production.

7	**CO2 infrastructure** > CO2 storage	Depleted oil and gas reservoir	Depleted oil and gas reservoir	High	Hide

CO_2 storage involves permanent retention of CO_2 in underground geological reservoirs (> 800 meter deep). The main types of geological reservoirs suitable for CO_2 storage are deep saline formations and depleted oil and gas reservoirs.

Cross-cutting themes: CCUS

Key countries: United States, Canada, Norway, China, Australia, Saudi Arabia, UAE, Brazil

Key initiatives:

- Full-scale demonstration has been implemented, as part of the Regional Carbon Sequestration Partnership in the United States, as part of an initiative to stimulate regional CO_2 storage.
- Examples include the In Salah project in Algeria.

Announced cost reduction targets:

- No cost reduction targets have been identified

10	**CO2 infrastructure** > CO2 transport	Pipeline	Pipeline	Very high	Hide

CO_2 transport connects CO_2 from capture sites with geological storage locations or sites where CO_2 is used. Pipelines are a cost effective way to transport large volumes of CO_2. Before pipeline transport, CO_2 is compressed to increase the density of the CO_2, thereby making it easier and less costly to transport.

Cross-cutting themes: CCUS

Key countries: United States, Norway, Canada, Netherlands

Key initiatives:

- In North America, an extensive network of over 7,000 km of pipelines transports around 60 $MtCO_2$ per year, primarily for enhanced oil recovery.
- Experience with CO_2 pipeline transport also exists in other countries, either for CO_2-EOR purposes (e.g. Brazil, Canada, China) or dedicated geological storage of CO_2 (e.g. Australia, Canada, Norway), but on a smaller scale.
- The Alberta Carbon Trunk Line provides a model for constructing oversized pipeline infrastructure to account for future needs. That pipeline has a capacity of 14.6 Mt/year even though only a fraction of that capacity is currently needed.
- The Acorn Project, United Kingdom aims to reuse 420 km offshore pipeline to connect St. Fergus with an offshore storage site.

Deployment targets:

- Several projects around the world involve development of CO_2 clusters and hubs in which CO_2 transport infrastructure could be shared.
- In its ACCA21 Roadmap, the Chinese Ministry of Science and Technology targets having a pipeline tranportation capacity of 20 Mtonnes/year of CO_2 with a total length in excess of 2 000 km. By 2050, those targets increase to 1 Gtonne/year capacity and a total length of more than 20 000 km.

Announced cost reduction targets:

- No cost reduction targets have been identified

9	**CO2 infrastructure** > CO2 storage	Saline formation	Saline formation	Very high	Hide

CO2 storage involves permanent retention of CO2 in underground geological reservoirs (> 800 meters deep). The main types of geological reservoirs suitable for CO2 storage are deep saline formations and depleted oil and gas reservoirs.

Cross-cutting themes: CCUS

Key countries: United States, Canada, Norway, China, Australia, Saudi Arabia, UAE, Brazil

Key initiatives:

- Saline formations have been used for CO2 storage at commercial scale in a number of CCUS projects (Sleipner, Snøhvit, Quest). The following projects exemplify the ambition of leading players to develop much larger (5 to 50 MtCO2/yr) storage operations:
- The Northern Lights project involves an offshore saline storage site beneath the Northern North Sea. The project involves two phases: for phase 1 a storage rate of up to 1.5 MtCO2/year is planned; during phase 2 the storage rate will rise up to 5 MtCO2/yr.
- The CarbonNet project is developing a deep saline CO2 storage site within the Gippsland Basin in Victoria, Australia, with a capacity of 125 MtCO2. A hub-based network centred on a large capacity pipeline will be capable of delivering 5 MtCO2/yr.
- The CarbonSAFE is a United States initiative focused on development of geological storage sites with CO2 capacities of over 50 MtCO2 across the continental US. The development CarbonSAFE is expected to lead to injection by 2026.

Announced cost reduction targets:

- No cost reduction targets have been identified

Serviceerhverv

Varmepumper/fjernvarme i serviceerhverv

Se under *Varmepumper/fjernvarme i husholdninger*

Fremstillingserhverv og bygge-anlæg

Energieffektivisering i procesenergi og intern transport

Se under *Energibesparelser i husholdninger*

Elektrificering i procesenergi og intern transport

10	**Industry** > Cross > cutting	Production > **High temperature heating** > Electromagnetic heating for large-scale industrial processes > Induction	Production	High	Hide

During induction, an electromagnetic field is generated when AC current flows through an inductor: this induces a current flow in a conductive material appositely placed nearby. The higher the current flow, the more the heat generated inside the object itself. If the field is raised enough to overcome the melting point, the material changes phase: this technology is used commonly for the melting of metals. While already commercial for some applications, research and development could expand the range of applications, further improve efficiency and reduce costs.

Cross-cutting themes: **Direct electrification**

Key countries:

Deployment targets:

- The National Steel Company (NASCO) in Saudi Arabia upgraded its technology to achieve a capacity of 1 million Mt, partly through an Induction Furnace of 20 t in combination with Electric Arc Furnace (EAF).
- The Indian company Viraj, one of the largest manufacturers of stainless steel, runs induction furnaces since its establishment in 1992, providing high quality products worldwide.
- The German Company ABP is a global induction technology manufacturer and provides several steel producers with induction furnaces, such as the chinese one Tisco with the installation of the world's strongest medium-frequency induction furnace system (with six 60 t induction furnaces and a 42 MW power supply)
- Inductotherm is a leading producer of induction furnace technologies.
- Induction heating is also being investigated for non-metals related applications. For example, Boeing has developed an induction process for molding thermoplastic composites, which significantly reduces energy requirements.

4	Industry > Cement and concrete	Production > Cement kiln > Electrification (direct)	Production	Moderate	Hide

Kilns - the main unit producing clinker for cement production - require high temperature heat and typically run on fossil fuels. Exploration is underway to electrify the heating process, through technologies such as the plasma arc or resistance-based heating.

Cross-cutting themes: Materials, **Direct electrification**

Key countries: Sweden, United Kingdom, Norway

Key initiatives:

- CemZero is a project developed by Swedish cement producer Cementa and energy utility major Vattenfall, launched in June 2017 with the aim to reduce carbon dioxide emissions. As feasibility study has indicated that electrification of the heating process is technically possible and that any future electrification of Cementa's factory on Gotland would work well together with the planned expansion of wind energy on Gotland. The feasibility study involved a test in a small-scale rotary kiln, in which clinker was produced with plasma heating. The project is continuing with an investigation on how a pilot plant can be built. It will test plasma technology in order to reduce technical risks and provide important information prior to scaling up and implementation.
- In February 2020, the Mineral Products Association (a UK trade association) was awarded 3.2 million pounds by the UK government to test hydrogen, biomass and electricity use in cement production. Physical trials were launced at two sites operated by Tarmac and Hanson Cement - one of hydrogen and biomass used together, and the other of electrical plasma energy and biomass used together. The trials follow a 2019 feasibility study that found a combination of 70% biomass, 20% hydrogen and 10% plasma energy could eliminate fossil fuel CO2 emissions from cement manufacturing. In September 2021, the Hanson Cement project reported successful completion of the trial, having operated the kilns using only net zero fuels (a mix of meat and bone meal, glycerine and tanker-delivered hydrogen).
- The ELSE project, a collaboration between Norcem, the University of Southeastern Norway and SINTEF, was initiated in Norway in 2018 to investigate the possibility and conditions for partially electrifying cement production. The technical feasibility study found that electrification of the calcination process in a precalcincer cement kiln is likely possible using resistance-based heating. Work on the project is ongoing, including developing an outline of a pilot plant.

9	**Industry** > Cross > cutting	Production > Low to medium temperature heating > Large-scale heat pump	Production	Very high	Hide

Large, industrial sized heat pumps can use renewable energy from air, water or ground but also waste energy from buildings and processes to provide heating and cooling. Heat pumps are considered large if they exceed capacities of 100 kW. Current technology can easily reach the one to several megawatt range with the largest units providing 35 MW in a single machine.

Cross-cutting themes: Renewable heat, District energy, Direct electrification

Key countries: Denmark, Sweden, Germany, Norway

Key initiatives:

- Skjern has a total capacity of 5,2 MW, and achieves a plant COP between 6,5 and 7
- Seawater is used in the first DHC project using an ultra-low GWP refrigerant, in a heat pump of 16 MW and a COP of 4.4
- Nagold heating and cooling system is highly innovative, providing 100% of building heating and cooling demands by regenerative energy source through a 101 kW heat pump

Deployment targets:

- Deployment: 25% share in DH by 2050 (Heat Roadmap Europe)

Announced cost reduction targets:

- Performance: Targets focus on perfomance of components

9	**Industry** > Cross > cutting	Production > Low to medium temperature heating > Electromagnetic heating for large-scale industrial processes > Infrared	Production	High

Infrared radiation transmits heat through electromagnetic waves, heating objects directly, without the need to first heat the air in order to transmit heat to a means higher heat transfer rates and faster time response, producing zero on-site emissions. Electric infrared radiation (IR) ovens offer an efficient and cost- alternative to convection ovens. In addition, they can provide fine control of IR wavelength in order to match specific requirements of an application. While commercial for some applications, research and development could expand the range of applications, further improve efficiency and reduce costs.

Cross-cutting themes: Direct electrification

Key countries: United States

Deployment targets:

- A pipe fitting plant located in Anniston, Al, with the support from Alabama Power, recently introduced electric infrared heating at their facility to dry p after the painting process. They replaced a gas-fired convection oven that was causing several stops to the production lines (due to maintainance of g and emissions), and saw significant productivity increase as well as reduction in maintenance. The estimated payback time is less than 1 year.

9	Transport > **Shipping**	Operations > Cold Ironing	Operations	High	Hide

When at berth, a ship still requires energy: for hotelling (e.g. cruise ships), refrigeration (refrigerated containers), on-board crane operation, etc. Associated power can be on the order of several megawatts. So-called "cold ironing" or Alternate Maritime Power (AMP) consists in plugging-in the vessel to the grid instead of running the auxiliary engine(s) of the ship. This also reduces noise and vibrations on-board, extends machinery lifetime and reduces engine maintenance needs. Dedicated installations, in the harbour and on-board are required. These must manage the variations in electric features (voltage, frequency, connectors). The use of fuel cells for port-side power has already been demonstrated.

Cross-cutting themes:

Key countries: United States, China, Europe

Key initiatives:

- Onshore: This technology is already available in at least about 100 berths worldwide: 64 in Europe, 24 in US, 9 in Asia.
- Onboard: All new cruise ships and all container ships bigger than 6000 TEU are already equipped with provision for cold ironing. Major shipping lines have also started retrofitting their ships.
- Wartsila, Cavotec, ABB, Terasaki are the main industries for this technology.
- Fuel cells have already been demonstrated for port-side power Source

Deployment targets:

- California has put in place regulations for cold-ironing since 2007 Source
- In China, since 2019, some categories of new-building vessels are to be equipped with a shore power system. Extended to other vessel types in 2020 Source
- In Europe, all ports are requested to provide cold ironing by the end of 2025 (Directive 2014/94/EU)

Announced cost reduction targets:

- Typical shore-side equipment provides 7-8 MW

Bio- og PtX-brændstoffer i intern transport
Konvertering til gas/PtX-brændsler i direkte fyrede processer

4	**Industry** > Cement and concrete	Production > Cement kiln > Partial use of hydrogen	Production	Moderate	Hide

Kilns - the main unit producing clinker for cement production - require high temperature heat and typically run on fossil fuels. Exploration is underway to replace a portion of the fossil fuels with hydrogen; the properties of hydrogen are such that it is not expected it could fully replace fossil fuel requirements.

Cross-cutting themes: Materials, **Hydrogen**

Key countries: United Kingdom

Key initiatives:

- In February 2020, the Mineral Products Association (a UK trade association) was awarded 3.2 million pounds by the UK government to test hydrogen, biomass and electricity use in cement production. Physical trials were launced at two sites operated by Tarmac and Hanson Cement - one of hydrogen and biomass used together, and the other of electrical plasma energy and biomass used together. The hydrogen triel with be at the Hason Ribbelsdale plant. The trials follow a 2019 feasibility study that found a combination of 70% biomass, 20% hydrogen and 10% plasma energy could eliminate fossil fuel CO2 emissions from cement manufacturing. In September 2021, the Hanson Cement project reported successful completion of the trial, having operated the kilns using only net zero fuels (a mix of meat and bone meal, glycerine and tanker-delivered hydrogen).
- CEMEX has piloted use of hydrogen in a kiln in Spain, and is now using hydrogen in its fuel mix in Europe, blended in small quantites. Plants to potentially use higher blends of hydrogen include the Rugby plant in the UK, which is set to be operational by mid 2021 using 100% alternative fuels (including biomass/waste and green hydrogen), and the Rudersdorft plant in Germany which is to be carbon neutral by 2030 as part of the Carbon Neutral Alliance project.

3	**Industry** > Aluminium	Manufacturing > Ancillary processes > Hydrogen for high-temperature heat	Manufacturing	Moderate	Hide

Hydrogen can be used to provide high temperature heat for anciliary processes, such as finishing processes (ex. rolling), and possibly also for alumina refining.

Cross-cutting themes: Materials

Key countries: Norway

Key initiatives:

- In May 2021, the aluminium company Hydro and hydrogen company Everfuel signed a Memorandum of Understanding to establish a framework for coordinated development and operation of electrolysers to produce hydrogen from renewables, to replace natural gas for heating purposes at Hydro's aluminium plants.

CCS i fremstillingserhverv

8	Energy transformation > **Power**	Generation > Biomass > CCUS > Post-combustion/chemical absorption	Generation	High	Hide

At a biomass-fired power plant with post-combustion capture using chemical absorption, the carbon dioxide is separated from the combustion flue gas by using a chemical solvent (e.g. amine-based). The CO2 is released at high temperature and the solvent regenerated for further operation.

Cross-cutting themes: CCUS, CO2 removal

Key countries: United Kingdom, Japan

Key initiatives:

- Pilot and demonstration scale:
- Drax Power Station, UK. Four of Drax's six 660 MWe units have been converted from coal to 100% biomass, with the other two units remaining on coal. CO2 capture is being piloted at Drax, with the intention for the biomass units to operate in the future as BECCS units Source .
- Mikawa power plant, Japan: original 50-MW coal power plant with CO2 capture has been converted to 100% biomass, with plans to have carbon capture operational in 2020.

9	**Industry** > Chemicals and plastics	Methanol > Production > CCUS > Chemical absorption	Methanol	High	Hide

Chemical absorption of CO2 is a common process operation based on the reaction between CO2 and a chemical solvent (e.g. amine-based). The CO2 is released at temperatures typically in the range 120°C to 150°C and the solvent regenerated for further operation.

Cross-cutting themes: Materials, CCUS, CO2 removal

Key countries: Brazil, Bahrain

Key initiatives:

- We are not aware of projects currently use this capture technology in methanol production linked with CO2 storage - thus the technology is at TRL 5 for the full CCS chain, in contrast to TRL 9 for CCU.

Deployment targets:

- Multiple commercial coal-based methanol plants use chemical absorption as part of the production process, putting the capture technology itself at TRL 11. We are aware of two projects subsequently using the CO2, putting the CCU chain at TRL 9.
- A QPC Quimica methanol plant in Brazil has been capturing CO2 since 1997 using amine-base capture. Food-grade CO2 is supplied to local soft drink manufacturers.
- At a methanol plant in Bahrain, owned by Gulf Petrochemicals Industries Company, a CO2 capture project began in 2007, using the Mitsubishi KS-1 amine-based solvent. The CO2 is used to enhance methanol and urea production.

7	**CO2 infrastructure** > CO2 storage	Depleted oil and gas reservoir	Depleted oil and gas reservoir	High	Hide

CO2 storage involves permanent retention of CO2 in underground geological reservoirs (> 800 meter deep). The main types of geological reservoirs suitable for CO2 storage are deep saline formations and depleted oil and gas reservoirs.

Cross-cutting themes: CCUS

Key countries: United States, Canada, Norway, China, Australia, Saudi Arabia, UAE, Brazil

Key initiatives:

- Full-scale demonstration has been implemented, as part of the Regional Carbon Sequestration Partnership in the United States, as part of an initiative to stimulate regional CO2 storage.
- Examples include the In Salah project in Algeria.

Announced cost reduction targets:

- No cost reduction targets have been identified

10	**CO2 infrastructure** > CO2 transport	Pipeline	Pipeline	Very high	Hide

CO2 transport connects CO2 from capture sites with geological storage locations or sites where CO2 is used. Pipelines are a cost effective way to transport large volumes of CO2. Before pipeline transport, CO2 is compressed to increase the density of the CO2, thereby making it easier and less costly to transport.

Cross-cutting themes: CCUS

Key countries: United States, Norway, Canada, Netherlands

Key initiatives:

- In North America, an extensive network of over 7,000 km of pipelines transports around 60 MtCO2 per year, primarily for enhanced oil recovery.
- Experience with CO2 pipeline transport also exists in other countries, either for CO2-EOR purposes (e.g. Brazil, Canada, China) or dedicated geological storage of CO2 (e.g. Australia, Canada, Norway), but on a smaller scale.
- The Alberta Carbon Trunk Line provides a model for constructing oversized pipeline infrastructure to account for future needs. That pipeline has a capacity of 14.6 Mt/year even though only a fraction of that capacity is currently needed.
- The Acorn Project, United Kingdom aims to reuse 420 km offshore pipeline to connect St. Fergus with an offshore storage site.

Deployment targets:

- Several projects around the world involve development of CO2 clusters and hubs in which CO2 transport infrastructure could be shared.
- In its ACCA21 Roadmap, the Chinese Ministry of Science and Technology targets having a pipeline tranportation capacity of 20 Mtonnes/year of CO2 with a total length in excess of 2 000 km. By 2050, those targets increase to 1 Gtonne/year capacity and a total length of more than 20 000 km.

Announced cost reduction targets:

- No cost reduction targets have been identified

Energistyrelsen

9	**CO2 infrastructure** > CO2 storage	Saline formation	Saline formation	Very high	Hide

CO2 storage involves permanent retention of CO2 in underground geological reservoirs (> 800 meters deep). The main types of geological reservoirs suitable for CO2 storage are deep saline formations and depleted oil and gas reservoirs.

Cross-cutting themes: CCUS

Key countries: United States, Canada, Norway, China, Australia, Saudi Arabia, UAE, Brazil

Key initiatives:

- Saline formations have been used for CO2 storage at commercial scale in a number of CCUS projects (Sleipner, Snøhvit, Quest). The following projects exemplify the ambition of leading players to develop much larger (5 to 50 MtCO2/yr) storage operations:
- The Northern Lights project involves an offshore saline storage site beneath the Northern North Sea. The project involves two phases: for phase 1 a storage rate of up to 1.5 MtCO2/year is planned; during phase 2 the storage rate will rise up to 5 MtCO2/yr.
- The CarbonNet project is developing a deep saline CO2 storage site within the Gippsland Basin in Victoria, Australia, with a capacity of 125 MtCO2. A hub-based network centred on a large capacity pipeline will be capable of delivering 5 MtCO2/yr.
- The CarbonSAFE is a United States initiative focused on development of geological storage sites with CO2 capacities of over 50 MtCO2 across the continental US. The development CarbonSAFE is expected to lead to injection by 2026.

Announced cost reduction targets:

- No cost reduction targets have been identified

Transport

Elektrificering og brint i vejtransport

9	**Transport** > Road	Vehicle-aircraft-vessel and components > Battery electric vehicle > Passenger car	Vehicle-aircraft-vessel and components	Very high	Hide

See Lithium-Ion battery

Cross-cutting themes: Direct electrification

Key countries:

9	**Transport** > Road	Vehicle-aircraft-vessel and components > Battery electric vehicle > Light commercial vehicle	Vehicle-aircraft-vessel and components	Very high	Hide

See Lithium-Ion battery

Cross-cutting themes: Direct electrification

Key countries: China, Germany, France

Key initiatives:

- In 2019, there were almost 377 000 e-LCVs on world's roads. China has the largest electric LCV fleet worldwide (65% of the fleet). Many major postal and package delivery companies, among them Amazon, DHL, DB Schenker, FedEx, the Ingka Group (who own Ikea), UPS, and the Swiss and Austrian postal services, have pledged to expand their electric fleets, through retrofits or outright purchases, in the near future.

9	**Transport** > Road	Vehicle-aircraft-vessel and components > Battery electric vehicle > Urban transit bus	Vehicle-aircraft-vessel and components	Very high	Hide

See Lithium-Ion battery

Cross-cutting themes: Direct electrification

Key countries: China

Key initiatives:

- In 2019, there were 513 000 e-Buses on world's roads. China has the largest electric bus fleet worldwide (95% of the fleet).

8-9	**Transport** > Road	Vehicle-aircraft-vessel and components > Battery electric vehicle > Truck	Vehicle-aircraft-vessel and components	Very high	Hide

See Lithium-Ion battery

Cross-cutting themes: Direct electrification

Key countries: China, United States, Germany, France

Key initiatives:

- In 2020, cumulative global deliveries of electric heavy-duty trucks totaled more than 30 000; the vast majority in China. Most of these are battery electric trucks, and most are MFTs. BYD, Cummins, Daimler, Emoss, and Fuso were the earliest manufacturers with models entering customer trials or the market. The Tesla Semi is perhaps the most well-known BEV HDT model soon on the market.

9-11	**Transport** > Road	Vehicle-aircraft-vessel and components > Battery electric vehicle > Battery > Lithium-ion	Vehicle-aircraft-vessel and components	Very high	Hide

This is currently the most common battery technology for electric vehicle applications and portable electronics. The anode is typically composed of graphite and various cathode chemistries coexist (Lithium iron Phosphate, Nickel Cobalt Aluminium Oxide, the most common being Nickel Manganese Cobalt (NMC)). Within NMC cathodes, the elements can be found in various proportions. These range, for example, from NMC111, with equal shares of N, M and C, to NMC811, with mass composition ratios of N, M, and C of 8:1:1 -- with a current trend towards moving to lower cobalt content. This already quite mature technology is undergoing rapid cost decreases. Current costs range from 130-170 USD/kWh at pack level. The energy density of this technology is around 200-220 Wh/kg at the cell level (recent announcements suggest that densities close to 300 Wh/kg might be reached in the coming years). Battery re-use (e.g. second-life applications, for instance for energy storage) and/or recycling technologies and policies will be essential to ensure that batteries contribute to sustainability goals.

Cross-cutting themes: Electrochemistry, Materials, Systems integration, Storage

Key countries: China, Korea, Sweden, Japan, Finland, United States

Key initiatives:

- Several companies have manufacturing plants entirely dedicated to producing this type of battery. The number and size of the plants are both increasing, and plants being built in 2018 ranged in capacity from 8-32 GWh. There have been many announcements for further plant size increases in the 2020s (reference: Global EV Outlook 2019).

Deployment targets:

- The EV30@30 target of the Clean Energy Ministerial's Electric Vehicles Initiative is supported by eleven national governments that collectively aim at reaching 30% sales share for electric vehicles (to the exception of 2- and 3- wheelers) by 2030. (supporting contries: Canada, China, Finland, France, India, Japan, Mexico, Netherlands, Norway, Sweden, the United Kingdom). Reference: Source

Announced cost reduction targets:

- Cost: US DOE: 80 USD/kWh Source

8-9	**Transport** > Road	Vehicle-aircraft-vessel and components > Hydrogen fuel cell electric vehicle > Hydrogen tank	Vehicle-aircraft-vessel and components	High	Hide

Hydrogen tanks are needed to store hydrogen on board vehicles in a gaseous form. Due to its low volumetric energy density, hydrogen requires very high pressure storage (between 35 and 70 Mpa). The challenges related to hydrogen tanks are safety (as H2 under pressure poses a fire risk, especially in case of leakage), durability (materials and components are needed that allow hydrogen storage systems with a lifetime of 1500 cycles, according to the US DOE [Source, certification and standardisation by component suppliers for vehicle Original Equipment Manufacturers, further reductions in tank weight and optimisation of shape and space in the vehicle (e.g. through alternatives to the current cylindrical shape). The industry response to the tank safety challenge is standardisation and modularity, which translates into, for example, buses being fitted with up to 10 individual cylindrical tanks.

Cross-cutting themes: Hydrogen, Fuel Cell

Key countries:

Key initiatives:

- There are a number of established hydrogen tank manufacturers (e.g. Faurecia, Cevotec, Doosan).

Deployment targets:

- 10 million FCEV by 2030 (2nd Hydrogen Energy Ministerial Meeting - Global Action Agenda, Source)

Announced cost reduction targets:

- Hydrogen storage tank production costs: The costs of current on-board storage systems (including fittings, valves and regulators) are estimated at USD 23/kWh of useable hydrogen storage at a scale of 10 000 units per year, decreasing to USD 14–18/kWh at a scale of 500 000 units per year (Vijayagopal, Kim and Rousseau, 2017: Source. The US DOE has an ultimate target of USD 8/kWh. Hydrogen storage system cost (DOE ultimate target): USD 8/kWh H2

7-8	**Transport** > Road	Vehicle-aircraft-vessel and components > Hydrogen fuel cell electric vehicle > Truck	Vehicle-aircraft-vessel and components	High	Hide

See PEM fuel cell

Cross-cutting themes: Hydrogen, Fuel Cell

Key countries: Japan, Korea, Germany, United States, Sweden

Key initiatives:

- The first-of-a-kind commercial hydrogen fuel cell truck developed by Hyundai has obtained 1600 orders for Swiss market Source
- Daimler, Fuso, Hyundai, Fuso, Toyota, Scania, Volkswagen, and PSA are developing FCEV trucks, ranging from prototypes to commercial models. The California-based truck start-up Nikola has managed to secure substantial funding and many pre-orders for its semi-trucks. Scania has recently delivered class 7 FCEV trucks to Norway. Hyundai Motor and H2 Energy aim to provide 1 000 fuel cell electric trucks to the Swiss market by 2023. Scania, Daimler, and California-based Nikola also have models at various stages between prototype and customer trials. FedEx and UPS are trialling fuel cell range-extender Class 6 delivery vehicles, and in Europe, the h2Share project is demonstrating several heavy trucks over 12 t.

Announced development targets:

- See PEM fuel cell

Announced cost reduction targets:

- See PEM fuel cell

9	**Transport** > Road	Vehicle-aircraft-vessel and components > Hydrogen fuel cell electric vehicle > Polymer electrolyte membrane fuel cell	Vehicle-aircraft-vessel and components	High	Hide

A hydrogen fuel cell system generates electric power from hydrogen. Fuel cell electric vehicles (FCEV) have much smaller batteries than battery electric vehicles (at least by a factor of 10), as the energy is stored in the hydrogen. By exploiting the higher gravimetric energy density of hydrogen, FCEVs can offer a higher ranges than BEVs. However their continuing deployment faces multiple technical and economic challenges, including: safety of hydrogen handling (refuelling, residual leakage), on-board hydrogen storage (see the dedicated entry below) and the high cost of the fuel cell stack (the electrochemical reaction inside the stack requires a proton exchange membrane (PEM) coated with a platinum-based catalyst, a costly material) and system. Costs of the fuel cell stack and system are expected to decline significantly with economies of scale. For FCEVs to be competitive with other powertrain technologies, hydrogen must be delivered to hydrogen refuelling stations at prices that bring per kilometre costs into the same range as conventional ICEs, or of battery electric vehicles powered by grid electricity. This will require further cost reductions in technologies for low- and zero-carbon hydrogen production technologies (e.g. SMR with CCS, renewable electricity generation such as wind and solar coupled to electrolysers), as well as in hydrogen transmission and distribution networks and in hydrogen refueling stations (HRS).

Cross-cutting themes: Electrochemistry, Hydrogen, Fuel Cell

Key countries: Japan, Korea, North America

Key initiatives:

- Fuel cell manufacturers: Ballard, Symbio (joint venture between Michelin and Faurecia), among others.

Deployment targets:

- By 2030:
- 95,000 fuel cell trucks on European roads (2% of total stock).
- An order of magnitude of 10,000 new fuel cell truck sales per annum (c. 7% of annual sales)
- 5 million light-duty FCEVs operating by 2030 (1.5% of total stock)
- 750,000 new fuel cell LDV sales per annum (c. 5% of annual sales) Source

Announced cost reduction targets:

- In the US: USD 30/kW for passenger cars USD 60/kW for medium- and heavy-duty trucks (US DOE, 2019: Source">Source), with revision for durability emerging from the DOE's latest end-of-year review: http://www.energy.gov/sites/prod/files/2019/06/f63/fcto-satyapal-overview-for-ecs-meeting-2019-05-27.pdf (slides 28-30) In Europe: EUR 45/kW for passenger cars < EUR 40,000 for complete system (fuel cell + tank) for buses Source

9	Transport > **Road**	Charging and refuelling > Hydrogen Refuelling Station	Charging and refuelling	Moderate	Hide

Normally, hydrogen refuelling stations (HRS) operate at 350 or 700 bars. Most of the stations for passenger cars are designed for operating at 700 bar, while stations for buses typically use 350 bar. For this reason, currently the majority of the stations operate at 700 bars, with many of them operating on a dual basis, being able to deliver fuel to both at 350 and 700 bars. Hydrogen refuelling can be standalone, or linked to a hydrogen production station. If they hydrogen is delivered to the station in intermediary form, storage and compression systems are needed. Hydrogen storage systems are generally low pressure, around 50-200 bar. Compressors overcome the pressure difference between storage and refuelling (which can be up to 1000 bar), and they are a central area of innovation in hydrogen refuelling stations. Most of the time, storage buffers (at 450 or 950 bars) are used to refuel vehicles (without a direct connection of vehicles to compressor outlet). A range of technologies can be employed for compressing H2 from low pressure states to up to those needed at the point of use, depending on whether hydrogen is in gaseous or liquid form, and on the throughput vehicle type. High levels of purity are needed in fuel cell applications, so technologies like ionic compressors are needed to reduce the possibility of contamination. During compression the hydrogen gas heats up, and precooling systems are needed to stay within the limits of the vehicle's fuel storage system. These systems add complexity and increase energy consumption, and are a key area of development in improving the efficiency and reducing costs of hydrogen refuelling systems.

Cross-cutting themes: Hydrogen

Key countries:

Key initiatives:

- At the end of 2020, 540 hydrogen refuelling stations (HRS) were in operation worldwide. There has been a considerable increase when compared with the number of stations available in operation at the end of 2019 (460). Japan remains the leading country in this sector with 137 stations, followed by Germany (90) and China (85). Both Japan and China have considerably expanded the number of stations in operation (24 each). Leading countries have announced targets to build a total of 1 000 hydrogen refuelling stations during 2025-30. Technology leaders include Linde, Air Liquide, or Nikola Motors which has announced a refuelling network for trucks in the US.

Elektrificering og brint i søfart

7	Transport > **Shipping**	Vehicle-aircraft-vessel and components > Hydrogen fuel cell electric vehicle > Solid Oxide	Vehicle-aircraft-vessel and components	Very high	Hide

Solid Oxide Fuel Cells (SOFC) run at very high temperature (500-1000 degrees Celsius). This fuel cell has low sensitivity to impurities, thus being able to run with hydrogen, methanol, LNG and diesel. It has a high cost (compared to other fuel cell technologies for maritime applications), can have medium size and has a moderate lifetime. Typical efficiency is 60% and this can be optimised to 85% with heat recovery (source: Source).

Cross-cutting themes: Hydrogen, Fuel Cell

Key countries:

Key initiatives:

- SOFC development by Thyssenkrupp and Sunfire: MS Forester cargo ship, in the framework of E4Ships SchIBZ project has received a Diesel fuelled SOFC Source
- Bloom Energy and Samsung Heavy Industries Team Up to Build Ships Powered by Solid Oxide Fuel Cells Source
- Samsung announced new SOFC ship. Source

3	Transport > **Shipping**	Charging and refuelling > Bunkering > Hydrogen	Charging and refuelling	High	Hide

Establishing a hydrogen bunkering infrastructure is an important step in introducing hydrogen propulsion in ships. However, vessels have not yet been designed, and there isn't currently a bunker vessel standard to work to. The technology systems depend entirely on the method for hydrogen storage (liquid or compressed gas). A vessel that has bunker tanks for liquid hydrogen needs a liquefied hydrogen supply. Compressed gas could be refuelled by a liquid hydrogen bunker vessel equipped with a regasification plant, or if stored as gas in the port, transferred by pressure balancing or compressing the gas into the ship. The choice of hydrogen storage method has implications for the technology used to power the vessel. A gas engine is preferred for liquid hydrogen as the excess heat from combustion can be used to evaporate hydrogen. Gaseous hydrogen generally works better with on-board fuel cells, even if can also be made suitable for gas engines, particularly if co-fired with natural gas. Cost-effective liquefaction chains for hydrogen are key for bunkering, as liquid hydrogen is expected to offer advantages over pressurized hydrogen gas in relation to transportation costs. In contrast with LNG where the gas is transported into the port, the economics of hydrogen mean that hydrogen liquefaction plants are likely to be located close to port, requiring stronger integration between systems.

Cross-cutting themes:

Key countries:

7	Transport > **Shipping**	Vehicle-aircraft-vessel and components > Hydrogen fuel cell electric vehicle > Molten Carbonate	Vehicle-aircraft-vessel and components	High	Hide

Molten Carbonate Fuel Cells (MCFC) operate at very high temperature (600-700 degrees Celsius). They have medium sensitivity to impurities and are flexible with regards to fuel choice. MCFC are very costly (compared to other fuel cell technologies for maritime applications). They can have large modules (up to 500 kW of power) and have a good lifetime. Their typical efficiency is around 50% and this can be optimised to 85% with heat recovery (source: Source . Due to limited power output, this technology is likely to be used preferably for small and medium vessels, as currently proved by the ongoing demonstrations.

Cross-cutting themes: Hydrogen, Fuel Cell

Key countries:

Key initiatives:

- MCFC fuel cells are being developed and tested:
- Large prototype tested on-board the offshore supply vessel "Viking Lady" Source
- MC-WAP Project (Fincantieri), MCFC fuelled by diesel Source

7	Transport > **Shipping**	Vehicle-aircraft-vessel and components > Hydrogen fuel cell electric vehicle > Proton Exchange Membrane	Vehicle-aircraft-vessel and components	High	Hide

This type of vessels is operated by a hydrogen fuel cell. Due to limited power output, this technology is likely to be used preferably for small and medium vessels, as currently proved by the on-going demonstrations. Different fuel-cell types exist and their names reflect the materials used in the electrolyte membrane. DNV GL evaluated 7 fuel-cell technologies and concluded that the following are the most promising for maritime applications (source: Source). According to the study from DNV-GL, Proton exchange membrane (PEM) fuel cell is considered a mature technology. Its operating temperature is 50-100 degrees Celsius, and has a typical efficiency of is 50-60% and a moderate lifetime. It has medium sensitivity to impurity, thus requiring hydrogen as a fuel, and a low cost (compared to other fuel cell technologies for maritime applications). Manufacturing compact fuel cells with high output power is quite challenging. Thus this technology is likely to be used preferably for small and medium vessels.

Cross-cutting themes: Hydrogen, Fuel Cell

Key countries:

Key initiatives:

- FCS Alsterwasser 5-year lake demonstration project (GER) (Source: Source)
- Hyseas III project (UK)
- Ballard & ABB have a joint demonstration projects for a hydrogen FC tugboat Source
- Norwegian Public Roads Administration has initiated a development project aiming to have the first hybrid H2 fuel cell ferry in commercial operation in 2021 Source
- Water-Go-Round has been launched. Source

9	**Transport** > Road	Vehicle-aircraft-vessel and components > Ethanol-fuelled diesel engine	Vehicle-aircraft-vessel and components	High	Hide

Specifically applied to heavy duty tracking that can use bioethanol, ED95 engines can be fuelled by 95% ethanol and 5% additives (including ignition improvers). They are adapted diesel engines with high compression ratios, which are required to ignite the fuel. A dedicated injection system is also needed, to compensate for the lower energy density of ethanol.

Cross-cutting themes: Bioenergy

Key countries: Sweden

Key initiatives:

- Scania has been producing commercially-available trucks using ED95 for several years. They are currently producing the third generation of ED95 engines. Source

Deployment targets:

- Depends on ED95 fuel availability (fuel production and distribution)

Announced cost reduction targets:

- This technology does not show particular additional costs in comparison to diesel engines Source

8-9	Transport > **Road**	Vehicle-aircraft-vessel and components > Methanol-fuelled engine	Vehicle-aircraft-vessel and components	Moderate	Hide

Methanol engines (so-called "M100", as vehicles fuelled by 100% methanol) are similar in design to gasoline engines, with moderate changes: material compatibility to prevent corrosion, adapted injection system, a dedicated cold start device and strategy, and adapted after-treatment for exhaust gas. Due to the high octane of the fuel, methanol engines can benefit from a high compression ratio, thus increasing thermal efficiency, possibly up to higher levels than for diesel engines. Methanol engines generate very low particulate emissions levels due to the molecule's specificity of having a single carbon atom - just as in the case of methane. The methanol is in liquid form at standard temperature and pressure, making it relatively easy to handle and store, although it is toxic for humans. Methanol can be produced as a biofuel or as a synthetic fuel (from electrolysis from low-carbon electricity with a carbon source). However, the availability of sustainably sourced biomass to produce methanol is limited.

Cross-cutting themes: Bioenergy, Hydrogen

Key countries: China

Key initiatives:

- Methanol-adapted combustion engines are a technically-validated technology. In 2012, the Chinese government initiated a methanol vehicle pilot program led by the Ministry of Industry and Information Technology (MIIT). In 2019, a government plan has been launched to expand the "M100" fleet. Source">Source The Chinese car manufacturer Geely has invested in a factories with production capacity of more than 300,000 methanol cars annually. http://www.methanol.org/wp-content/uploads/2019/03/A-Brief-Review-of-Chinas-Methanol-Vehicle-Pilot-and-Policy-20-March-2019.pdf In Europe, only R&D programs are still running. These aim to address concerns on material compatibility to prevent corrosion, adapted injection system, a dedicated cold start device and strategy, and adapted after-treatment for exhaust gas.

Deployment targets:

- By 2050, Concawe targets adoption of e-fuels (excluding hydrogen) of up to 30% of the fuel demand in Europe. E-methanol is one of these e-fuels (see: Source)

9	Transport > **Road**	Vehicle-aircraft-vessel and components > Gas-fuelled engine > Truck > Liquefied biogas	Vehicle-aircraft-vessel and components	Moderate	Hide

This technology can be applied in to vehicles (typically for heavy-duty applications) powered by an internal combustion engine, and fuelled by biomethane. The biomethane is stored in cryogenic tanks, which enables it to be storage at a higher energy density than compressed methane and is a cost-efficient solution for long-haul trucks. The liquefied biomethane powertrain, including dedicated piston engine, direct injection device and cryogenic tank, faces some technological challenges: * insulation of on-board liquefied biogas (LBG) storage in cryogenic tank (-162 degrees Celsius) * risk of methane slip and incomplete methane combustion (requires combustion system optimisation and dedicated exhaust after-treatment). Methane slip can also occur from liquefied natural gas (LNG) tank, which releases the evaporative phase methane under high pressure if the engine is not capable to use it. For this technology to deliver net emissions reductions, the methane should be produced from renewable sources, as use of fossil methane in current engine technologies has no CO2 emissions benefit relative to diesel powertrains. Exhaust gas after-treatment catalysts should also be enhanced to compensate for the fact that oxidising of methane molecules is difficult, especially at low temperatures (e.g. during engine warm-up, or when the engine is running at low loads). Indeed, since after-treatment of stoichiometric combustion is a far more cost-effective option for reducing methane and other pollutant emissions than both direct injection and diesel lean combustion, most current research efforts focus on enhancing after-treatment systems. As an example, see Source

Cross-cutting themes: Bioenergy

Key countries:

Key initiatives:

- Some truck manufacturers are offering liquefied gas trucks (which can work with 100% biomethane). There are available products and prototypes from e.g. Volvo, Scania, Iveco (truck manufacturers) and from Westport (LNG technology supplier). See for example:
- VOLVO FH LNG: Source
- IVECO Stralis NP 460: Source
- SCANIA: Source

Announced cost reduction targets:

- Current LNG powertrain costs (including tank) are about twice as high as conventional diesel powertrains (Source Westport, see Source

9	Transport > **Road**	Vehicle-aircraft-vessel and components > Gas-fuelled engine > Truck > Compressed biogas	Vehicle-aircraft-vessel and components	Moderate	Hide

This technology can be applied in vehicles (typically heavy duty) powered by an internal combustion engine, fuelled by biomethane. The biomethane is stored in a tank kept at high pressure (20-25 MPa). Technical challenges that apply to this technology mostly relate to methane slip (leakage) in the engine, which occurs at the inlet manifold (before the actual air supply to the cylinder) and from the cylinder due to incomplete combustion. Low pressure premixed injection engines have higher slip (5% unburnt methane in the exhaust gas) than direct injection high pressure gas engines (reference: Advanced Motor Fuels Technology Collaboration Programme Annex 51). For this technology to deliver net emissions reductions, the methane would need to be produced from renewable sources (e.g. biomethane or synthetic methane) and burned in direct injection high pressure gas engines, as use of fossil methane in current engine technologies has no CO2 emissions benefit relative to diesel powertrains. Further technology development to avoid gas slip from the manifold are also required. Exhaust gas after-treatment catalysts should also be enhanced to compensate for the fact that oxidising of methane molecules is difficult, especially at low temperatures (e.g. during engine warm-up, or when the engine is running at low loads). Indeed, since after-treatment of stoichiometric combustion is a far more cost-effective option for reducing methane and other pollutant emissions than both direct injection and diesel lean combustion, most current research efforts focus on enhancing after-treatment systems. As an example, see Source .

Cross-cutting themes: Bioenergy

Key countries: Italy, Sweden

Key initiatives:

- Already available products and prototypes from truck manufacturers:
- Volvo has developed a truck equipped by a direct injection high pressure gas engine Source
- Westport has developed a high pressure direct injection engine Source

Announced cost reduction targets:

- Current CNG powertrain costs (including tank) are about 70% higher than conventional diesel powertrains (Source Westport, see Source

Bio- og PtX-brændstoffer i søfart

4-5	Transport > **Shipping**	Vehicle-aircraft-vessel and components > Ammonia-fuelled engine	Vehicle-aircraft-vessel and components	Very high	Hide

Combustion engines fuelled with ammonia could represent a carbon free solution for ship propulsion, particularly for long distance ocean going merchant ships. Ammonia is the most traded chemical commodity, thus operators already have expertise in handling it. Its storage and transport infrastructure is well deployed. Ammonia is over 50% more energy-dense per unit of volume than liquid hydrogen, therefore potentially more suitable as a transport fuel than hydrogen. It is stored at -33 degrees Celsius, which is higher than the storage temperatures required for natural gas and hydrogen (-153 degrees Celsius and -253 degrees Celsius, respectively). Nevertheless, challenges remain, especially related to the hard-to-ignite combustion process and a low flame speed.

Cross-cutting themes: Hydrogen

Key countries: Denmark, Finland

Key initiatives:

- Some engine manufacturers are committed to rapidly develop ammonia ICEs:
- MAN ES is developing an two-stroke ammonia engine and aims at commercialising it by 2024. This will be followed in 2025 by a retrofit package that enables existing vessels to be retrofitted to run on ammonia (Source
- Wartsila is doing similar work with both its mid-size dual fuel and spark-ignited engines, with a view to produce them for marine and generators. It expects to develop the engine capable of runnign solely on ammonia by 2023. (Source ; Source Various shipbuilders have announced the development of very large vessels running on ammonia with ICE, often in conjunction with MAN ES. Below some:
- the American Bureau of Shipping (ABS) projects to design a Chittagongmax container carrier of 2 700 TEU capacity Source
- the Lloyds Register (LR) granted Approval in Principle to Dalian Shipbuilding Industry Co. for an NH3-fuelled 23 000 twenty-foot equivalent unit ultra-large containership concept design Source
- LR awarded Approval in Principle to the Shanghai Merchant Ship Design & Research Institute for the design of a 180 000 tons bulk carrier – a design SDARI claims to have already completed. The project also involves MAN ES.
- MISC, Samsung Heavy Industries, Lloyd's and MAN joined forces in 2020 on to make an ammonia-fuelled tanker commercial by 2030 Source ; Source

9	Transport > **Shipping**	Charging and refuelling > Bunkering > Ammonia	Charging and refuelling	Very high	Hide

Ammonia is easier to store than hydrogen. It can be stored in a liquid form in pressurized tanks (1 Mpa, ambient temperature) or at ambient pressure with a temperature of -33 degrees Celsius (instead of -253 degrees Celsius for H2). Refrigeration techniques are required, not cryogenics. Ammonia offers a higher volumetric energy content compared to hydrogen (+70%). Ammonia is already produced and transported in large quantities around the world. Therefore, bunker supplies could in theory be readily accommodated.

Cross-cutting themes:

Key countries:

Key initiatives:

- It benefits from an already existing infrastructure and distribution network (due to its industrial use, mainly for fertilizer synthesis).
- A set of industries has signed a memorandum of understanding to develop the supply chain for ammonia bunkering in Singapore (Source

Deployment targets:

- Ammonia should represent more than 75% of the energy consumption of shipping sector beyond 2050 Source

Announced cost reduction targets:

- Ammonia plant investment cost: 2.6 -3.1 billion USD (7000 tpd) Source

8-9	Transport > **Shipping**	Vehicle-aircraft-vessel and components > Methanol-fuelled engine	Vehicle-aircraft-vessel and components	Moderate	Hide

Power for propulsion comes from engine(s) fuelled by methanol. Methanol has relatively high energy density and is compatible with existing engines after moderate adaptation, thus not posing problems for bunkering, on-board storage and combustion. Attention has to be paid to safety, as methanol is toxic.

Cross-cutting themes: Bioenergy, Hydrogen

Key countries: Denmark

Key initiatives:

- Maersk has placed an order for 8 large ocean-going containerships capable of running with methanol. Hyundai Heavy Industries is going to deliver the vessels by 2024, with the option of additional 4 vessels in 2025 (Source
- Some methanol tankers are able to run on both methanol and conventional fuels. They are fitted with MAN 6G50ME-B9.3-LGI engines and a dual-fuel concept developed together with Marinvest Source
- Stena Line has experienced a ferry ("Stena Germanica") that can be fueled either by diesel or methanol (see Source and Source
- There are also ocean-going vessels fitted with methanol-compatible machinery: Source

Announced cost reduction targets:

- The additional capital expenditure (CAPEX) for the dual fuel capability, which enables the vessel to run on methanol, will be about of 10-15% of the total price (Source.

9-10	Transport > **Shipping**	Vehicle-aircraft-vessel and components > Biogas-fuelled engine	Vehicle-aircraft-vessel and components	Moderate	Hide

In liquefied biogas internal combustion engine ships, propulsion and auxiliaries are powered by an engine running on natural gas. As of today, the majority of engines in operation are low-pressure dual fuel, which are characterised by methane slips that limit the GHG mitigation potential of this powertrain. The adoption of direct injection high pressure engines could limit the slip Source

Cross-cutting themes: Bioenergy

Key countries:

Key initiatives:

- Several vessels are already fuelled by LNG. Given that liquefied biogas is chemically equivalent to LNG, no major adaptations to the vessel's powertrain are required.

Deployment targets:

- Possibly up to 23% (expressed in terms of required energy for the shipping sector, see DNV GL: Source

Bio- og PtX-brændstoffer i luftfart

Affald

Genanvendelse og affaldsreduktion

10	Industry > **Cross** > cutting	Metallic products > End-of-life > New recycling techniques for better separation and reduced contamination > Novel physical separation	Metallic products	Moderate	Hide

While the separation of ferrous metals from non-ferrous metals is relatively easy thanks to the magnetic properties of the ones containing iron, recovering precious and valuable metals takes more technologically advanced and sophisticated recycling equipment. New physical separation techniques can better sort materials, such as through shredding with more selective component breaking and and mechanisms to reduce entangling.

Cross-cutting themes: Material efficiency

Key countries:

Deployment targets:

- The company BHS-Sonthofen has developed a new procedure to increase the amount of copper recovered from internal winding of electric motors. This new procedure features a Rotorshredder for this process, subsequent materials separation, and the purification of copper in a rotor impact mill. In particular, the rotor impact mill (RPMX) from BHS is well suited to removing impurities from copper fractions extracted from the material. This is an upgrade to the traditional rotor impact mill, a high-performance crusher with a vertical shaft, a higher circumferential speed and a smaller milling gap. Copper wires can also be processed, even though their small size had made it difficult to recycle them until now.

9	Industry > **Cross** > cutting	Metallic products > End-of-life > New recycling techniques for better separation and reduced contamination > X-ray transmission	Metallic products	Moderate	Hide

While the separation of ferrous metals from non-ferrous metals is relatively easy thanks to the magnetic properties of the ones containing iron, recovering precious and valuable metals takes more technologically advanced and sophisticated recycling equipment. X-ray tranmission technologies sort materials according to differences in their density, enabling detection of grains of metals with much smaller sizes than before.

Cross-cutting themes: Material efficiency

Key countries: Germany

Deployment targets:

- The company TOMRA Sorting launched in 2019 a new machine, X-TRACT X6 FINES, that improves the sorting of high-purity mixed non-ferrous metal fractions. The unit incorporates enhanced high-speed X-ray transmission (XRT) technology, which can detect and sort grains of metal that are almost half the size of what was previously sortable. This process identifies the atomic density of the materials regardless of their thickness. Extensive testing in high throughput applications demonstrated the unit's ability to consistently achieve unrivalled purity levels of 98-99%.

10-11	**Industry** > Battery recycling	Copper recycling > Extraction from cables > Ultrasonic separation	Copper recycling	Moderate	Hide

The ultrasound cavitation effect is used to separate the plastic. The rapid succession of compression and vacuum waves generate cavitation bubbles which help separate the different elements. Efficient and no pollution.

Cross-cutting themes:

Key countries:

Key initiatives:

- Already in use by Hielscher. Only for small scale.

9	**Industry** > Chemicals and plastics	End-of-life > New recycling techniques with reduced downcycling > Chemical depolymerization for polystyrene	End-of-life	Moderate	Hide

This chemical recycling technology uses chemicals to break down polymers into monomers. Techniques vary in the amount of heat and pressure used, but generally considerably less heat is used compared to pyrolysis.

Cross-cutting themes: Material efficiency

Key countries: Canada, United States

Deployment targets:

- Agilyx Corporation and INEOS Styrolution have developed a recycling process based on depolymerization of polystyrene waste, which is now commercially available. The first plant opened in 2018 in Oregon in the United States. Several other plants are at different stages of development.

9	Industry > **Chemicals and plastics**	End-of-life > **New recycling techniques with reduced downcycling** > **Pyrolysis**	**End-of-life**	Moderate	Hide

Pyrolysis is the breakdown of material at high temperatures in the absense of oxygen. Pyrolysis can be used to convert mixed plastics wastes into liquid hydrocarbons, which can be used again by the petrochemical industry.

Cross-cutting themes: Material efficiency

Key countries: Italy, Finland, Germany, Belgium, US, Netherlands, Austria, Spain, Saudi Arabia, Malaysia, Norway

Key initiatives:

- Versalis, a chemical company owned by Italy oil company Eni, launched in early 2020 the Hoop project, in which it will build a pilot scale plant (6 kt/yr) in Mantova using a pyrolysis technology developed by engineering company Servizi di Ricerche e Sviluppo.
- The Finish refining company Neste anncouned in 2019 partnerships with Germany waste management company Remondis and Belgian recycler Ravago in order to develop thermochemical recycling technologies.
- LyondellBasell (a US-run company with headquarters in Netherlands) is building a small-scale pilot plant in Italy to test its proprietary pyrolisis-based recycling technology, MoReTec, developed in partnership with Germany's Karlsruhe Institute of Technology.
- Austrian oil company OMV is testing its thermal cracking recycling process, called ReOil, at a pilot plant that began operation in 2018. Chemical company Borealis is partnering with OMV on developing the technology.

Deployment targets:

- The Thermal Anaerobic Conversion (TAC) technology, which was developed by UK-based company Plastic Energy and converts end-of-life plastics to oil (called Tacoil), is in use at two commercial-scale plants in Spain (operational since 2014 and 2017). Plans are underway to develop another plant in Netherlands in cooperation with Saudi Arabian company SABIC, as well as a plant in Malaysia in partnership with Petronas.
- Norwegian company Quantafuel has developed a technology that combines pyrolysis with catalysis to convert mixed plastic wastes to synthetic fuels. Its first commercial plant started operating in late 2019 in Denmark and will process 18 kt of plastic waste a year. The company has backing from companies such as major chemical producer BASF.
- Dutch company Fuenix Ecogy Group has developed a pyrolysis-based recycling technology. In mid 2019, it entered into a parternship with the chemical company Dow to supply its pyrolysis oil feedstock to Dow's production facility in Terneuzen Netherlands.

7	**Industry** > Chemicals and plastics	End-of-life > New recycling techniques with reduced downcycling > Solvent dissolution for PET	**End-of-life**	Moderate	Hide

Solvent is used to separate out the polymer, then it is purified in a liquid state (similar to purifying drinking water). The polymer is not depolymerized (broken into its component monomers), but rather purification removes colour, odor and contaminants from plastic waste in order to extract a virgin-quality polymer.

Cross-cutting themes: Material efficiency

Key countries: United Kingdom

Key initiatives:

- The British company Worn Again Technologies is developing a pilot R&D facility, due to be operational in 2021, to validate and develop its proprietary process, which will separate, decontaminate and extract PET polymer from polyester textiles, bottles and packaging. The technology uses a solvent at an elevated temperature.

CCS på affaldsforbrændingsanlæg
Se under *CCS i fremstillingserhverv*

Landbrug, gartneri, skove og fiskeri

Fodertilsætningsstoffer
Håndtering af gylle og gødning
Udvidet lavbundspotentiale
Fordobling af det økologiske areal
Brun bioraffinering som for eksempel pyrolyse
Dyrkning af plantebaserede fødevarer og planteprotein
Yderligere skovinitiativer
Energieffektiviseringer i procesenergi og intern transport i landbruget
Elektrificering i procesenergi og intern transport i landbruget

Andet

Regneeksempel for DAC (baseret på 1 GW havvind)

6	CO_2 infrastructure > **Direct air capture**	Liquid DAC (L-DAC)	Liquid DAC (L-DAC)	Moderate	Hide

Liquid direct air capture (L-DAC) is a technology aiming at capturing CO_2 from the atmosphere and either use it as a feedstock or store it underground. This technology relies on water hydroxide solutions with a strong affinity for CO_2 (e.g. sodium hydroxide, calcium hydroxide and potassium hydroxide). These water solutions allow the continuous operation of the DAC system, with potentially long contactor lifetimes despite atmospheric contaminants. On the other hand, they rely on regeneration systems working at very high operating temperatures (around 900°C).

Cross-cutting themes: CCUS, CO_2 removal

Key countries: Canada, United States, United Kingdom

Key initiatives:

- Carbon Engineering Source started operating their first pilot plant in 2015. The same plant has also been used (since 2017) to provide CO_2 for fuel production (Fischer Tropsch syncrude, suitable for refining into diesel and jet). The company is offering an offset mechanism where individuals and entities can pay a subscription to remove a certain amount of CO_2 from the atmosphere for permanent geological storage. Carbon Engineering is developing the first large-scale DAC plant in the United States in partnership with Occidental Petroleum. The plant will capture up to 1 $MtCO_2$ each year and could become operational as early as 2024. Carbon Engineering's DAC technology will also be employed in the Storegga's Dreamcatcher Project in the United Kingdom, aiming at carbon removal.

Announced cost reduction targets:

- According to Carbon Engineering, their commercial scale plant will reach a capture cost below 200 USD/tCO_2.

6	CO_2 infrastructure > **Direct air capture**	Solid DAC (S-DAC)	Solid DAC (S-DAC)	Moderate	Hide

Solid direct air capture (S-DAC) is a technology aiming at capturing CO_2 from the atmosphere and either use it as a feedstock or store it underground. This technology relies on amine materials bonded to a porous solid support. CO_2 is initially chemically bounded to the solid filter, and then released once the filter is saturated by warming it up to 80-100°C and reducing the pressure.

Cross-cutting themes: CCUS, CO_2 removal

Key countries: Switzerland, Germany, Iceland, Italy, Netherlands, United States, Oman, Chile, Norway

Key initiatives:

- Two companies, respectively based in Switzerland and United States, are currently offering S-DAC solutions: Climeworks Source and Global Thermostat Source
- Climeworks has commissioned fifteen plants, at pilot, demonstration and commercial scales. Most of them are focusing on DAC for CO_2 use, however the recently launched Orca plant in Iceland is removing CO_2 from the atmosphere (4000tCO_2/year) by permanently storing it through its mineralisation within basalt formations. Climeworks is currently offering an offset mechanism where individuals and entities can pay a monthly subscription to remove a certain amount of CO_2 from the atmosphere and turn it into stone (current price between USD 600-1000/tCO_2). Their DAC technology will be employed by 2024 in the production of synthetic fuels (up to 3 million litres) by the Norsk e-Fuel AS consortium in Norway.
- Global Thermostat has been operating a number of pilot plants (three) and is currently collaborating with ExxonMobil to advance their technology and investigate its scalability and economic uses for the capture of CO_2. Their technology will be employed by 2022 in the HIF's Haru Oni eFuels Pilot Plant in Chile (producing synthetic fuels from electrolysis based hydrogen production and air captured CO_2).

Announced cost reduction targets:

- Climeworks: the company's target for large-scale DAC deployment is between USD 200-300/tCO_2 by 2030 and below USD 200/tCO_2 by 2040.
- Global Thermostat: The company is expecting to lower capture cost once their cumulative capacity reaches 1 $MtCO_2$.