ENERGY TRANSITION

Updated

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INTRODUCTION

"We have always been wrong about the future of the petroleum industry. Not just a little bit wrong, totally wrong".

Day 4 in the course
World Fiscal Systems for Oil and Gas

INTRODUCTION

The petroleum industry faces four important challenges in the development of energy transition strategies:

-- ever cheaper renewables

-- ever cheaper energy storage

-- competition from hydrogen

-- climate change policies

This presentation will first discuss these challenges in detail.

INTRODUCTION

Subsequently, the following issues will be reviewed:

-- the impact on the petroleum industry

-- the transformation of the petroleum industry, and

-- the required industry and government reorganization to deal effectively with energy transition.

Finally, the resulting changes to energy and petroleum fiscal policies will be discussed as well as the possibility for new Petroleum Energy Arrangements.

RENEWABLE ENERGY DEVELOPMENTS

Renewable Energy Economics

An important issue that will define the future of the petroleum industry is the competition with renewable energy. The main renewable sectors are solar, wind and hydropower.

It is very important to realize that the overall economic structure of the upstream petroleum industry is very different from the solar and wind industries.

This different structure will largely determine the outcome of the competition.

RENEWABLE ENERGY DEVELOPMENTS

Renewable Energy Economics

The petroleum industry is a high-risk industry justifying a high rate of return. Weighted Average Cost of Capital (“WACC”) is typically in the 8 – 15% range.

The exploration phase is very high risk and can only be done on an equity basis.

The development phase is high risk and high tech. Project financing can usually only be obtained for a modest percentage of the development capital expenditures and therefore requires large equity investment. Resource estimates could vary over a wide range (P10 – P90).

Even the production phase is subject to significant risk and operating costs are a significant part of the overall cost structure.

The petroleum business requires considerable technical expertise and capital resources to enter the business.

RENEWABLE ENERGY DEVELOPMENTS

Renewable Energy Economics

The solar and wind industries are relatively low risk industries with a WACC in the 4 – 10% range, largely depending on country risk and debt/equity ratios.

No exploration is required, although some sites are better than others. Development risk of the project is similar to building any construction project. Although the production of wind turbines and high-quality solar panels is a high-tech operation, the actual construction of wind and solar farms is low tech and low risk.

Operating costs are low for solar and moderate for wind. Operating risk are low once the project is underway.

It is therefore relatively easy for any company to enter this business.

RENEWABLE ENERGY DEVELOPMENTS

Renewable Energy Economics

The economics of a wind or solar project depends on the LCOE (the average lifetime levelized cost of electricity generation). The LCOE is calculated as a pipeline tariff as follows:

LCOE = NPVCOS@x%/EP@x%. NPVCOS is the net present value at the discount rate of x% (the WACC) of the cost of service of the plant. The cost of service includes the depreciation, debt return, equity return, operating costs and taxation. EP is the electricity production also discounted at x%. This creates a levelized costs per MWh or kWh.

One way to obtain renewable energy is on the basis of power purchase agreements (PPA's), whereby the bidder offers the lowest PPA price. Remarkable low prices have been obtained.

RENEWABLE ENERGY DEVELOPMENTS

Renewable Energy Economics

In the following slides the economics of the Renewable Industries will be discussed in more detail.

The discussion will be largely based on the detailed information provided by Lazard, IRENA (the International Renewable Energy Agency, located in Abu Dhabi) supplemented by information from BNEF (Bloomberg New Energy Finance) and some other sources.

For the main renewable energy resources, first the current economics will be discussed. Subsequently, further possible technology developments will be reviewed, and finally possible future costs will be estimated.

RENEWABLE ENERGY DEVELOPMENTS

Renewable Energy Economics – Technology Developments

The main driver of Renewable Energy Economics will be Technology Developments. Research has become very focused on:

1. **Lower solar costs**
2. **Lower wind costs**
3. **Lower battery costs with less expensive materials**
4. **Lower hydrogen costs, and**
5. **More efficient use of energy.**

Developments are going very fast. Almost daily new developments are being announced. So considerable emphasis will be placed on these matters in this PowerPoint.

RENEWABLE ENERGY DEVELOPMENTS

Renewable Energy Economics

In analyzing the results, it is important to compare with current costs of generating electricity based on fossil fuels or nuclear energy. The most comprehensive analysis in this respect is from Lazard which tabulates costs for the USA.

Lazard provides a complete overview of LCOE all energy sources, where applicable with and without subsidies.

Following slide provides the 2023 results. These results show that electricity generated from new solar utility scale and wind plants are now cheaper than from new combined cycle gas plants.

For small new diesel plants, the LCOE range in 2019 was 19.7 to 28.1 cents/kWh

RENEWABLE ENERGY DEVELOPMENTS

Renewable Energy Economics (2023)

Following are the ranges of LCOE for new-build plant and rooftop:

Solar PV Residential –11.7-28.2cents/kWh

Solar Commercial & Industrial – 4.9-18.5 cents/kWh

Solar PV Crystalline/ThinFilm Utility –2.4-9.6 cents/kWh

Solar PV+Storage Utility - 4.6 – 10.2 cents/kWh

Geothermal –6.1-10.2 cents/kWh

Onshore Wind –2.4-7.5 cents/kWh

Onshore Wind + Storage 4.2 – 11.2 cents/kWh

Offshore Wind – 7.2-14.0 cents/kWh

Natural Gas Peaking –11.5 – 22.1 cents/kWh

Coal - 6.8-16.6 cents/kWh

Nuclear –14.1-22.1 cents/kWh

Gas Combined Cycle – 3.9-10.1 cents/kWh

RENEWABLE ENERGY DEVELOPMENTS

Renewable Energy Economics (2021)

Lazard also compares the costs of new-build solar and wind with the marginal costs of continuing to operate fossil fuel and nuclear plants, indicating that it is cheaper to built a new solar plant than continuing to operate a coal fired power plant in the US.

New-build renewable plants:

Solar PV Thin Film Utility – 2.8 to 3.7 cents/kWh

Wind – 2.6 to 5.0 cents/kWh

Marginal Costs of fossil fuel and nuclear plants:

Coal – 3.7 to 4.7 cents/kWh

Nuclear – 2.4 to 3.3 cents/kWh

Combined Cycle Gas – 1.9 to 2.9 cents/kWh

RENEWABLE ENERGY DEVELOPMENTS

Solar Photovoltaics ("PV") – Types of Panels

There are four types of solar panels:

1. **Monocrystalline – These are made of a single pure silicon crystal cut into wafers.**
2. **Polycrystalline- These are several silicon crystals melted together.**
3. **PERC – Passivated Emitter and Rear Cell – this is a monocrystalline panel with a layer in the back that reflects light back into the cell creating higher efficiency; while PERT is the same concept but made of multicrystalline material.**
4. **Thin film – They are thin flexible panels made from different materials:**

    -- Cadmium telluride (CdTe)

    -- Amorphous silicon (a-Si)

    -- Copper indium gallium selenide (CIGS)

RENEWABLE ENERGY DEVELOPMENTS

Solar Photovoltaics (“PV”) – Types of Panels

There are four types of solar panels have the following efficiencies:

PERC	**- 25%+**
Monocrystalline	**- 20%+**
Polycrystalline	**- 15% - 17%**
CIGS	**- 13% - 15%**
CdTe	**- 9% - 11%**
a-Si	**- 6% - 8%**

RENEWABLE ENERGY DEVELOPMENTS

Solar Photovoltaics ("PV") – Types of Panels

There are four types of solar panels have the following costs pe Watt (not including installation and labor)

PERC	**- $ 0.32 - $ 0.65**
Monocrystalline	**- $ 1.00 - $ 1.50**
Polycrystalline	**- $ 0.70 - $ 1.00**
CIGS	**- $ 0.60 - $ 0.70**
CdTe	**- $ 0.50 - $ 0.60**
a-Si	**- $ 0.43 - $ 0.50**

RENEWABLE ENERGY DEVELOPMENTS

Solar Photovoltaics ("PV") – Types of Solar Cells

There are p-type and n-type solar cells.

A p-type solar cells dopes its silicon wafer with boron, which has one less electron than silicon, making the solar cell positively charges.

An n-type solar cells is doped in phosphorus which has one electron more than silicon, making the solar cell negatively charged.

P-type solar cells were initially developed for space applications since they are more resistant to space radiation, and this became the main type for residential and commercial use.

However, currently the trend is towards n-type solar cells, since they are more efficient and are not affected by light induced degradation.

Trendforce expects 210 mm n-type solar panels to be 78% of the market in 2024 and 82% of the market by 2027.

RENEWABLE ENERGY DEVELOPMENTS

Solar Photovoltaics ("PV") – Types of Solar Cells

There are also heterojunction (HJT) solar cells.

These are monocrystalline or polycrystalline cells sandwiched between to a-Si layers. This increases efficiency also above 20%.

A new development is TOPCON (tunnel oxide passivated contact) solar cells. These are the similar to typical PERT cells, but with an ultrathin layer of silicon added. N-type TOPCON cells can be upgraded from the n-type PERT cells.

In the presentation we will focus on Utility Scale Solar.

RENEWABLE ENERGY DEVELOPMENTS

Organic Solar Cells

An important alternative to the silicon based solar cells are organic solar cells.

Organic solar cells offer many benefits by being climate-friendly, inexpensive, lightweight and flexible.

They can be made transparent by not absorbing visible light but only infra-red light or ultra-violet or both.

The main drawback is relatively low efficiency. The Fraunhofer Institute achieved a record of 15.8%.

However, Kansas University in 2024 achieved 20% based on non-fullerene acceptors

RENEWABLE ENERGY DEVELOPMENTS

Solar Photovoltaics ("PV") – Types of Panels

How much KWh do solar panels produce?

This depend on the amount of equivalent direct sun light per day. For the various climates this could vary between 4 and 8 hours per day. A typical 400-Watt panel would therefore produce between 1600 and 3200 Watthours or 1.6 to 3.2 KWh.

It should be noted that one does not need direct sun for a panel to work. Even on shady days a panel produces 25 – 40% of the capacity output.

RENEWABLE ENERGY DEVELOPMENTS

Solar Photovoltaics ("PV") – Types of Panels

Temperature impacts on the efficiency. This is measured by the temperature coefficient. This is the loss of efficiency with every degree Celsius above 25 degrees.

Monocrystalline and Polycrystalline panels have a Temperature efficiency of -0.3% per degree Celsius to -0.5% per degree Celsius.

Thin film typically – 0.2% per degree Celsius.

Also, solar panels degrade over time, typically about 0.5% of their capacity per year. This means after a 25 to 30-year life the generation is 12 – 15% less.

RENEWABLE ENERGY DEVELOPMENTS

Floating Solar

In a number of cases solar energy is based on floating solar since this solves onshore location problems. Floating solar is slightly more efficient since the panels stay cool .

Floating solar in combination with hydropower reservoirs is also attractive since it protects the evaporation of water from the reservoir and can be combined with pumped storage.

RWE and SolarDuck intend to establish floating solar at sea among offshore wind turbines, with panels floating several meters high above the sea at the Dutch HKW wind farm.

A Belgian consortium has introduced SEAVOLT a concept of having floating solar under very harsh North Sea conditions based on high platforms. Crosswind (Shell and Eneco) is doing the same.

RENEWABLE ENERGY DEVELOPMENTS

Floating Solar - Costs

Indonesia installed in 2020, up to 90 MW units for a cost of 3.68 cents/kWh.

SVJN Green Energy has obtained a 90 MW solar project in Madhya Pradesh, India, for a PPA of 4.6 cents/kWh.

Singapore constructed in the Tengeh reservoir a floating solar park over 45 hectares. The 60 MW project generates 77,300 MWh for a project costs of $ 120.5 million. Power generation started in 2021 and the PPA is for a period of 25 years. Trina Solar installed 12,556 solar modules at the site.

The Indonesia Cirata floating solar project is now the largest in the world, expanding with 500 MW of power in addition to 192 MW already installed. The project is supported by Masdar and PLN NP of Indonesia.

RENEWABLE ENERGY DEVELOPMENTS

Floating Solar – Limitless Resource

-- It should be noted that the calm seas near the Equator, such as offshore Nigeria or Indonesia could generate limitless energy.

The offshore of Indonesia alone could generate 35,000 Twh per year; which is equal to the world energy consumption.

Only 25,000 square km of solar panels out of a total offshore area of 6,400,000 sq km would provide all electricity for Indonesia.

-- A UK Research Team from Bangor and Lancaster Universities calculated the potential of the world’s 68,000 lakes and reservoirs as 1302 TWh using only 10% of the surface areas up to a maximum of 30 km2.

RENEWABLE ENERGY DEVELOPMENTS

Floating Solar – Lake Projects

-- SJVN Green Energy Ltd of India (SGEL) and Ocean Sun of Norway are cooperating offshore India to test a new membrane-based floater technology, which may save considerable costs.

-- Pakistan is preparing a 500 MW plant at the Keenjhar Lake in Sindh.

--Thailand is planning 182 MW floating at the Srinagarind dam

-- Philippines is planning two floating plants for 250 MW

RENEWABLE ENERGY DEVELOPMENTS

Floating Solar – Offshore Projects

-- Solar Duck has started a $ 8.4 million 5 MW project offshore the Netherlands within the OranjeWind wind farm and is planning a 540 MW offshore solar and wind project offshore Calabria, Italy.

-- South Korea is planning the 1200 MW Saemangeum marine offshore floating solar plant behind a dam.

-- Grand Sunergy has commissioned the 400 MW offshore Yantai Zhaoyuan project in China in Laizhou Bay.

RENEWABLE ENERGY DEVELOPMENTS

Solar for space limited areas

Apart from rooftop solar and floating solar, there are several solutions being developed and applied for space limited areas, such as in Europe. Solutions are:

-- Vertical solar panels, oriented E-W to capture morning and afternoon sun,

-- Agrivoltaics:

-- see-through organic solar panels for greenhouses,

-- checker-board solar roofs for crops for shaded areas,

-- Walk-on solar footpaths with panels withstanding 2 tons of weight per panel, such as under construction in Groningen,

-- Solar covered parking lots and bike paths, France made it compulsory this year to cover all large parking lots with solar panels,

-- Solar panels in train tracks,

-- Solar windows, and

-- Solar roofs on cars: Kaneka solar panels of 180 cm2 and 26.6% efficiency will be installed on the Toyota Prius EV starting this year.

RENEWABLE ENERGY DEVELOPMENTS

Vertical Solar

-- The ground-mount solar installer Sunstall has launched Sunzaun, a company producing bifacial vertical solar systems, which are specifically beneficial for farms since the can be oriented East-West and do occupy very little land.

Research indicates that these panels can generate as much power as inclined south facing systems.

These panels can also be used along highways or railroads or even as residential fences.

-- In area where the surface of the lake is valuable or there are environmental limitations of lake surface use, vertical floating solar can be used as is done by the German company Sinn Power which plans to install a 1.8 MW facility in Gilching, Bavaria

RENEWABLE ENERGY DEVELOPMENTS

Solar Footpath

A Hungary company called Platio has installed a solar footpath in the city of Groningen in the Netherlands of 400 m2.

It consists of 2,544 monocrystalline Patio solar pavers with an efficiency of 21.8% and an annual output of 55,000 kWh.

The path can withstand a pressure of 2 tons without microcracks.

The pavers are good for footpaths, terraces, driveways and bike paths.

RENEWABLE ENERGY DEVELOPMENTS

Agrivoltaics

Agrivoltaics is the combination of solar power with agricultural activities in such a way that agriculture is not negatively affected and sometimes improved.

It could take three forms:

1. **Vertical solar panels installed in farms, not affecting in a major way agricultural activities.**
2. **Elevated solar panel strips which create shade below the panels during certain hours. Partial shading is good for a number of crops.**
3. **See-through solar organic panels for greenhouses, which are based on ultra-violet light and let normal light through for growing vegetables and other products.**

RENEWABLE ENERGY DEVELOPMENTS

Agrivoltaics

The Joint Research Center of the EU estimates that the agrivoltaics potential, using just 1% of the agricultural lands for agrivoltaic projects is 944 GW.

Italy, France and Germany have put regulations in place to promote agriculture.

A German farmer, Thomas Schmid has installed 2.5 km2 above a field cultivating wheat, grass clover, potatoes and celery and this project proved to be successful.

A pilot project near Lake Constance features 6 meter high panels permitting machinery to navigate below the panels.

As can be understood agrivoltaics installations are slightly more costly than basic ground mounted installations.

RENEWABLE ENERGY DEVELOPMENTS

Agrivoltaics

In the Dutch province of Noord Brabant, Groenleven a subsidiary of BayWa r.e. is installing an 8.7 MW project with 24,000 elevated panels to grow raspberries. The project will be operational in 2024.

Such projects are attractive since they avoid single-use plastic covers that would otherwise be used.

RENEWABLE ENERGY DEVELOPMENTS

Agrivoltaics

-- The University of Western Ontario has done extensive research with three different vertical panel spacings in three Canadian locations. The three spacings were 45, 15 and 5 meters.

The conclusion was that 5 meter spacing is too tight, and the larger spacings were OK.

There were no problems growing arugula, beets, bok choy, celery, coriander, collards, fava beans, kale, lettuce, parsley, parsnips, peas, swiss chard and thyme.

-- The Indian SRM Institute of Science and Technology did an economic analysis of agrivoltaics in India and came to the conclusion that the LCOE was only 3.9 cents/kWh with a 6 year payback of a system.

RENEWABLE ENERGY DEVELOPMENTS

Solar Utility Sized Photovoltaics ("PV") - Current Costs

International costs are also low in some areas of the world. The IRENA information indicates that so far for 2020 the average auction price (PPA) for solar utility size PV is 4.8 cents/kWh. The range is from about 2.8 cents to 10 cents per kWh.

Obviously, the costs of Utility Solar per KWh depend on the climate as well as local construction costs.

<u>Desert Areas:</u> PPA's of about 3 cents per KWh apply in Mexico. BNEF indicates that Solar PV committed in 2019 in Australia, China, Chile and the UAE may achieve LCOE's of between 2.3 and 2.9 cents/kWh. Dubai received an auction offer for 900 MW of 1.6953 cents/kWh and Qatar 1.449 cents/kWh for 800 MW. Early 2021, Saudi Arabia received a record low offer of 1.04 cents/kWh for the 600 MW Al Shuaiba project.

RENEWABLE ENERGY DEVELOPMENTS

Solar Utility Sized Photovoltaics ("PV") - Current Costs

<u>USA:</u> Lazard indicates an LCOE range of 2.8 to 4.1 cents/kWh for 2021, in 2022 costs went up an in 2022 typical attractive PPA's were about 4.2 cents/KWh.

<u>Chile:</u> The lowest bid in National Energy Commission 2024 bid round was for 1.332 cents/kWh for a solar project made by the Canadian Solar Libertador Solar Holding.

<u>Colombia:</u> In its 2024 bid round of the Ministry of Mines and Energy, the lowest bid for a solar project was 1.8 cents/kWh

<u>Israel:</u> EDF won a tender in 2024 at 1.9 cents/kWh

<u>Albania:</u> The lowest bid in a tender in 2024 was 3.97 cents/kWh

<u>South Africa:</u> had a sixth bid round in 2024 with an average price of 2.7 cents/KWh

RENEWABLE ENERGY DEVELOPMENTS

Solar Utility Sized Photovoltaics ("PV") - Current Costs

Europe: European prices in 2022 ranged from 3 -10 cents per kWh. Portugal received a bid of 1.3 cents/kWh for 670 MW. Germany received a bid in 2024 of 3.9 cents/kWh for utility-scale solar.

An interesting example of current costs is a 500 MW solar power plant being planned for construction in 2023 in Palloneva in Finland, indicating that as high north as 62.5 degrees latitude solar energy is economic. The LCOE is estimated to be $ 0.04/kWh.

Bangladesh: The Bangladesh Power Development Board is offering a PPA of 10.2 cents/kWh for 68MW.

India: Rajasthan Urja Vigas Nigam Ltd, has in 2023 awarded 1 GW of power for an average PPA of 3.2 cents/kWh.

Japan: a 2024 round at 3.4 cents/kWh and later 2.9 cents/kWh.

RENEWABLE ENERGY DEVELOPMENTS

Solar Utility Sized Photovoltaics ("PV") - Current Costs

<u>Canadian Arctic:</u> Another interesting example of a northern project is the Rio Tinto project for the creation of a solar project for the Diavik Diamon Mine in the Northwest Territories, 200 km south of the Arctic Circle.

The project generates electricity from sunlight and light reflected from the Arctic snow. The project will consist of 6,600 bifacial panels which will generate about 4.2 GWh; 25% of the consumption of the mine. No cost data were provided.

Rio Tinto is targeting to be net-zero worldwide by 2050.

RENEWABLE ENERGY DEVELOPMENTS

Solar Utility Sized Photovoltaics ("PV") - Current Costs

The examples of the previous slide indicates that the also the costs of international solar PV is now at and below the level of the cheapest new combined cycle gas plants in the USA.

However, it should be noted that due to current political and economic conditions the solar PPAs in Europe rose in 2022 third quarter on average to 6.86 cents per kWh, with the lowest prices in Spain at 3.9 cents per kWh and the highest in Poland at almost 10 cents per kWh. In the US the average rose to 4.57 cents per KWh in the fourth quarter of 2022.

However, in 2024 SECI in India awarded 1.5 GW for a PPA of 3.1 cents/kWh.

RENEWABLE ENERGY DEVELOPMENTS

Solar Utility Sized Photovoltaics ("PV") - Current Costs

Current costs of installing a complete solar project ranges from $ 600 per kW in India to $ 2000 per kW in Russia. On average about $ 1,100 per kW.

These costs include a complete project including:

-- hardware, such as the PV modules, inverters, racking and grid connection,

-- mechanical and electrical installation, and

-- soft costs, such as design, financing, permitting, the profit margin, etc.

Iberdrola started up in 2022 the "Francisco Pizarro" plant in Spain at 590 MW consisting of 1.5 million panels, costing 310 million US$, or $ 525 per kW.

RENEWABLE ENERGY DEVELOPMENTS

Solar Installed Capacity

Based on the IEA statistics the World Solar generation in 2020 was 833 TWh compared to 26762 TWh in total

This is distributed as indicated below

Solar Generation (TWh)		`	
	Total	Solar	(%)
WORLD	**26762**	**833**	3.1%
North America	**5221**	**134**	2.6%
United States	4243	117	2.8%
Central and South America	**1277**	**22**	1.7%
Brazil	605	8	1.3%
Europe	**3962**	**176**	4.4%
European Union	2757	142	5.2%
Africa	**827**	**10**	1.2%
Middle East	**1189**	**11**	0.9%
Eurasia	**1335**	**4**	0.3%
Russia	1057	1	0.1%
Asia Pacific	**12961**	**476**	3.7%
China	7787	270	3.5%
India	1609	64	4.0%
Japan	1003	79	7.9%
South East Asia	1111	18	1.6%

RENEWABLE ENERGY DEVELOPMENTS

Future Solar PV technologies: Perovskites

An enormous amount of research and development is underway to increase this efficiency to 30% with new technologies or find other ways to lower the cost of solar PV.

One development that seems promising is to work with perovskites. This is a mineral of which the crystal structure easily absorbs solar energy.

Very thin films can be made from solutions containing this mineral. Such solutions can simply be sprayed on surfaces with an inkjet. Saule Technologies is developing possible applications.

The Helmholtz Zentrum Berlin has already achieved a 32% efficiency for a combination silicon-perovskite cell; silicon absorbs better light in the red spectrum and perovskite in the blue spectrum, so a combination is an optimal way to increase efficiency.

The King Abdullah University of Science and Technology (KAUST) has achieved a 33.2% efficiency with a perovskite-silicon tandem solar cell.

RENEWABLE ENERGY DEVELOPMENTS

Future Solar PV technologies: Perovskites

The main attraction of perovskites is that the theoretical maximum efficiency is up to 66% and could be higher with further research. Also, it offers the possibility of low cost solar.

However, the full development still faces problems. These are:

-- material instability.

-- toxic materials used in production.

-- current-voltage hysteresis of perovskite cells.

However, more research may overcome these problems. A recent discovery made by Aditya Mohite of Rice University indicates that combining 2D and 3D layers of perovskites increase stability.

NREL of the US has reached 27.1% efficiency in an all-perovskite tandem solar cell.

RENEWABLE ENERGY DEVELOPMENTS

Future Solar PV technologies: Perovskites

-- The University of Toronto have developed a triple junction all perovskite solar cell with 23.3% efficiency.

Perovskite cells can be made of layers, with each layer tuned to a different light wavelength increasing the overall efficiency.

-- A team at KAUST (Saudi Arabia) has developed an inverted perovskite cell with 2D/3D heterojunctions with 25.6% efficiency.

-- A team of the University of Toronto and the Qingdao University in China have developed an all-perovskite solar cell based on carboranes reaching an efficiency of 27.2%.

-- A team from Nanjing University claims to have achieved 28.5% efficiency with a 3D/3D double layer perovskite heterostructure.

RENEWABLE ENERGY DEVELOPMENTS

Future Solar PV technologies: Perovskites-Silicon Tandems

-- The Ecole Polytechnique Fédérale de Lausanne (Switzerland) has produced a perovskite-silicon tandem cell with 30.9% efficiency.

-- Longi claimed on the SNEC trade show in Shanghai in 2024 that it had achieved a 34.6% efficiency for a perovskite-silicon tandem.

-- The Fraunhofer Institute for Solar Energy Systems has determined that future perovskite-tandem cells could achieve an efficiency of 39.5%.

RENEWABLE ENERGY DEVELOPMENTS

Future Solar PV technologies: Perovskites

-- The Chinese manufacturer CGL Technologies stated in 2024 that there perovskite-silicon tandem module would cost 50% of the crystalline silicon model, which was $0.15 per Watt, so it would costs $ 0.075 per Watt.

-- It is a 1 by 2 meter panel with an efficiency of 26%.

-- They intend mass production by 2025.

RENEWABLE ENERGY DEVELOPMENTS

Future Solar PV technologies: Iron Disilicide

Researchers at Rajshahi University in Bangladesh have developed a tandem solar cell based on cadmium telluride and iron disilicide which promises an efficiency of 43.9%.

RENEWABLE ENERGY DEVELOPMENTS

Future Solar PV technologies: Perovskites

Important discoveries were made in early 2023 and 2024:

- **A group of scientists led by the University of Toledo demonstrated that perovskite solar cells treated with DPPP retained a power conversion that was high and superior durability. DPPP is a widely available commercial product.**
- **Professor Amassian of North Carolina State University discovered a way to steer ions in a safe conduit that does not impair materials structural integrity or performance. This improves stability and operational performance.**

RENEWABLE ENERGY DEVELOPMENTS

First Perovskite Module Factories

-- Revkor of Miami, Florida, and H2 Gemini of Switzerland have announced the plan to built a 20 GW module factor based on HJT Perovskite cells in Salt Lake City, Utah, USA.

The target capacity of 20 GW is to be built in stages; the first stage of 5 GW is anticipated to be operational by 2024; the full capacity will be reached by 2026.

-- Renshine Solar is planning a Gigawatt scale plant in Changshu, Jiangsu province in China. It started a 150 MW production line in January 2024. Its modules have an efficiency of 18.4%.

RENEWABLE ENERGY DEVELOPMENTS

Future Solar PV technologies: 2023-2025

Initial further development of PERC solar cells will improve efficiencies. However, these cells will approach their theoretical efficiency limit of 24.5%.

Therefore, there will be a switch to n-type HJT and TOPCON cells that could achieve 24% to 26% efficiency by 2025 and much higher by 2030. Examples:

--SunDrive, an Australian company, has achieved a 26.41% efficiency using heterojunction technology. It also claims that its copper plating technology helps improve efficiency.

-- China’s DAS Solar reached 26.24% with an n-type TOPCON cell.

RENEWABLE ENERGY DEVELOPMENTS

Future Solar PV technologies: 2026-2030

By 2030 it can be expected that commercial solar cell efficiency will reach 30% as well as entirely new concepts may be introduced. Following are some developments:

-- the Chinese solar panel producer LONGI already reached an efficiency of 31.8% with a perovskite tandem cell on mono-silicon wafers.

-- Oxford PV will open a commercial 250 MW plant in late 2020 with Meyer Burger in Germany. In this case perovskites are simply sprayed on existing solar panels to make two-layer solar cells to try to increase efficiency to over 30%. Recently Oxford PV achieved 29.52% efficiency. Equinor is a shareholder of Oxford PV.

RENEWABLE ENERGY DEVELOPMENTS

Future Solar PV technologies: 2026-2030

--TNO, Eindhoven and Delft Universities in the Netherlands and R&D firm IMEC have developed a Perovskite-Silicon Tandem Device that has hit 30% efficiency.

--Scientists of the King Abdullah University of Science and Technology (KAUST) achieved 33.7% efficiency with a perovskite/silicon tandem cell in 2023.

-- LONGI announced 34.6% for perovskite-silicon tandem.

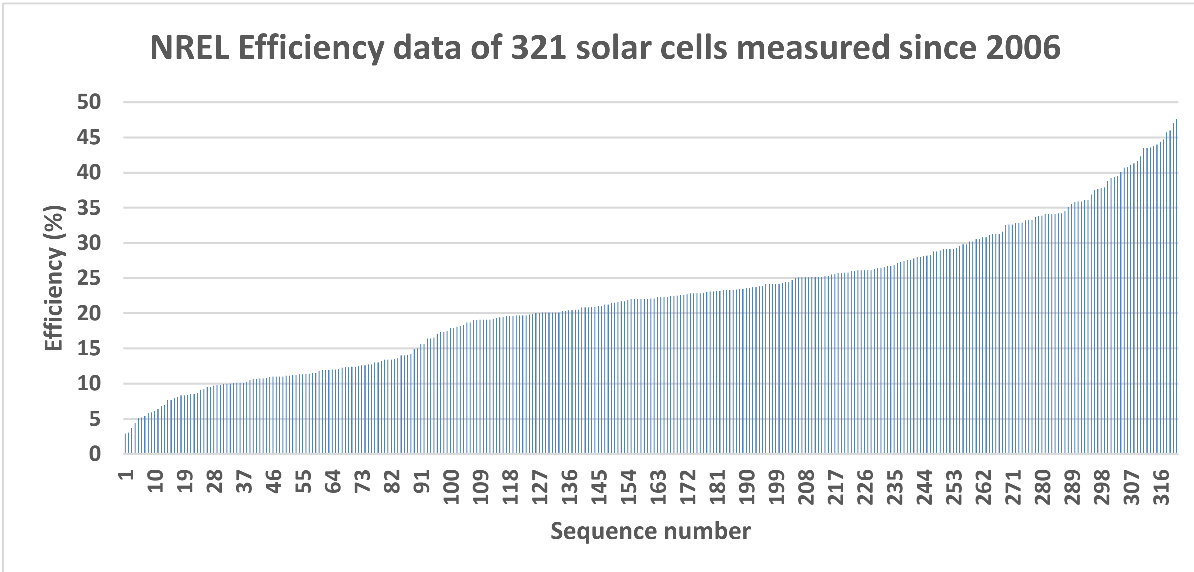
--Fraunhofer Institute and the Dutch research firm AMOLF have announced a multi-junction cell with an efficiency of 36.1%

--A Bangladesh team is developing a copper, indium, gallium and selenium cell with a potential capacity of 38.4%.

-- The Fraunhofer Institute indicates that a perovskite-silicon tandem cell could achieve 39.5% efficiency.

RENEWABLE ENERGY DEVELOPMENTS

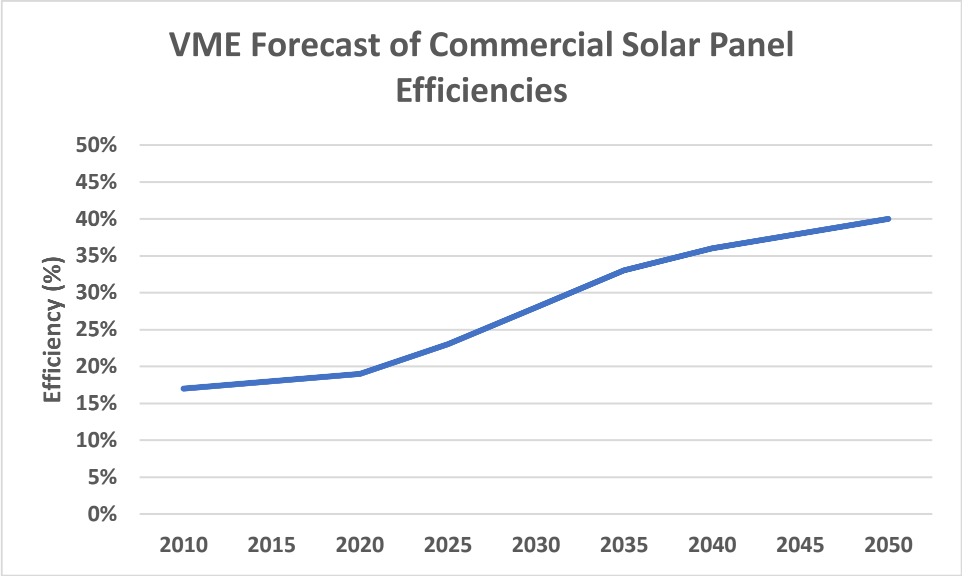
VME Forecast of solar panel efficiencies



The VME forecast of solar panel efficiencies is based on the data chart of the US National Renewable Energy Laboratory. They produce an overview of all efficiency measurements in their Best Research-Cell Efficiencies chart. The above chart reflects the NREL data of 321 measurements since 2006. The highest efficiency measured so far is 47.6%.

RENEWABLE ENERGY DEVELOPMENTS

VME Forecast of solar panel efficiencies



Solar panel efficiencies may reach 40% by 2050. This means a typical 4 KW residential system that required panels on 24 square meters before 2020, will by 2050 only require panels on 10 square meters.

RENEWABLE ENERGY DEVELOPMENTS

Future Solar PV Costs

It can be estimated that by 2030, solar utility-based PV will be able to produce power in the range of 0.9 – 8 cents per kWh, with a probable average LCOE of about 2.5 cents/kWh (2020$).

Due to strong technological developments the price of solar may drop faster and reach 1.5 cents/kWh by 2030. Such developments are predicted by DR Dahlmeier Financial Risk Management.

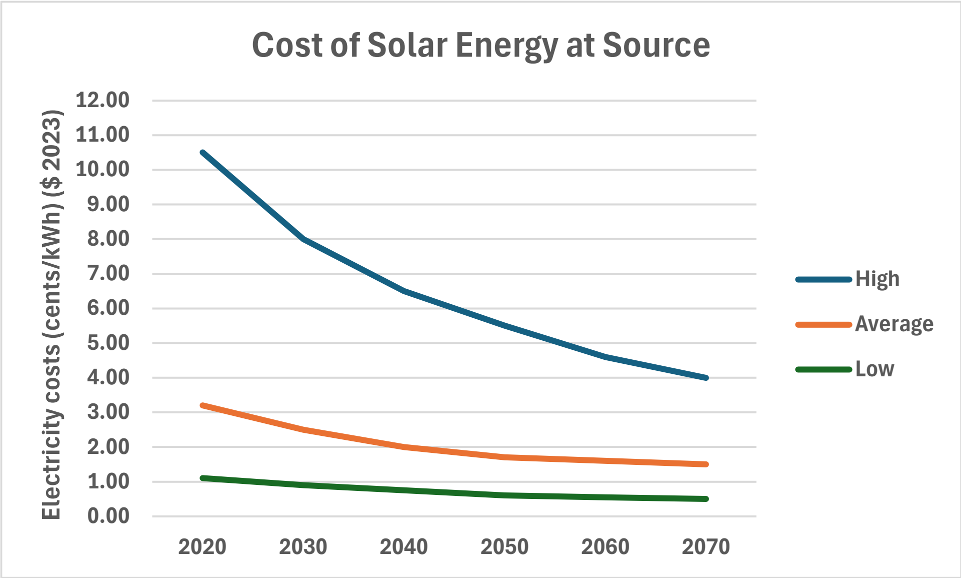
The research organization RMI predicts 2 cents/kWh by 2030.

New solar energy plants will deliver electricity at a significantly lower LCOE than any fossil fuel plant in the USA and below the marginal cost of coal and nuclear plants.

For 2050 solar PV may be in the range of 0.6 – 5.5 cents/kWh (2020$) with a possible average of 1.7 cents/kWh, below the marginal costs of any fossil fuel or nuclear plant.

RENEWABLE ENERGY DEVELOPMENTS

Future Solar PV Costs



The chart illustrates the estimate of the range of future solar costs at the exit of solar parks. The range is primarily due to geographical variation.

RENEWABLE ENERGY DEVELOPMENTS

Largest Solar Parks

Following is a summary of the largest solar parks in the world:

1. **Golmud Solar Park – China – 2.8 GW, with 7 million solar panels, they hope to achieve 16 GW in the next 6 years,**
2. **Bhadla Solar Park – India – 2.7 GW, spread out over 160 sq km, more than double the size of Manhattan,**
3. **Pavagada Solar Park – India – 2.05 GW**
4. **Mohammed bin Rashid Al Maktoum Solar Park – UAE – 1.63 GW over 76 sq km, they hope to expand to 5 GW by 2030.**
5. **Benban Solar Park – Egypt – 1.61 GW, costing $ 4 billion and having the best solar conditions at 6.3 kWh per m2 per day.**
6. **Abu Dhabi – Al Dhafra farm – 2 GW, consisting of 4 million bifacial panels, just put in operation before COP28.**

RENEWABLE ENERGY DEVELOPMENTS

Solar Exports

Some large solar export projects are being planned:

-- AAPowerLink is considering a 2671 undersea cable from the North West Territories in Australia to deliver solar electricity based on a capacity of 4.5 GW to Darwin and 1.5 GW to Singapore.

RENEWABLE ENERGY DEVELOPMENTS

Future Solar World Capacity

A study by NREL indicates that the 63.4 TW total solar capacity required by 2050 in order to achieve the decarbonization goals can indeed be achieved, based on silicon panels and new generation panels, such as perovskites.

RENEWABLE ENERGY DEVELOPMENTS

Wind Turbines – Types

There are basically three types of wind turbines:

- **horizontal axis – these are the typical wind turbines with a tower, a generator on top of the tower, a horizontal axis to attach the blades and the blades themselves. The come in all types of sizes and are used onshore, offshore fixed and offshore floating. They need to be pointed into the wind.**
- **vertical axis – these are blades spinning around a vertical axis with a generator at the bottom. They are omni-directional, which means they do not need to be pointed at the wind.**
- **A large box structure with multiple rotors catching wind.**
- **The Vortex Bladeless generator which is based on a flexible wobbling pole. Only applicable for very small capacities, such as for home use.**

In the presentation we will focus on utility wind generation.

RENEWABLE ENERGY DEVELOPMENTS

Wind – Costs – Wind Speed

The costs of wind energy depends directly on the typical speed of wind and the local costs of construction. Wind speeds vary considerably based on local conditions within a country.

Average onshore wind speeds are typically low (less than 4 meters per second) at the equator between 15 degrees North and South, and in Northern India, Eastern China and Eastern Russia. Average wind speeds outside these areas could vary from 4 – 10 meters per second outside these areas.

Many offshore areas in the Northern and Southern Hemisphere feature average windspeeds between 10 and 11.5 meters per second.

Areas with average windspeeds over 8 meter per second or more usually feature low costs wind. It should be noted that maximum wind speeds could be as much as 25 meters per second.

RENEWABLE ENERGY DEVELOPMENTS

Wind – Costs – Efficiency and Capacity Factor

The costs of wind energy depends furthermore on the efficiency of the wind turbine.

The efficiency is how much of the wind energy a turbine can convert to mechanical energy.

The maximum efficiency is determined by the Betz's Law which specifies that this is 59.3%.

Typical utility type wind turbines achieve 75 – 80% of this limit.

After conversion to mechanical energy the wind turbine needs to generate electricity. The capacity factor is the electricity produced divided by the maximum power capability, running full time at the rated power.

The capacity factor is a function of the windspeed. At high speeds it could be 70%. The capacity factor varies during the year. Onshore capacity factors range from 22% to 45%, offshore from 28% to 52%.

The total effect is the efficiency multiplied by the capacity factor. For instance, an 80% efficiency with a 40% capacity factor would have a total conversion effect of 32% of the 59.3% or 19% of the original wind energy.

RENEWABLE ENERGY DEVELOPMENTS

Onshore Wind – Current Costs

International costs for onshore wind are low. The IRENA information indicates that so far for 2020 the average auction price (PPA) for Onshore Wind is 4.5 cents/kWh. The range is from about 1.8 cents to 9.0 cents per kWh. The BNEF data base shows an average of 4.4 cents/kWh for 2020.

A report of the US Department of Energy indicates that in 2022 the prices in the "wind belt" are now as low as 2 cents/kWh.

For the first quarter of 2023 the P25 LevelTen index is $ 51.12/MWh.

The latest bid round organized in Turkey for a 1000 MW wind farm resulted in a price of 3.48 cents per kWh.

Onshore wind prices in Europe varied early 2022 between 3.45 cents/kWh in Sweden to 6.4 cents/kWh in the UK.

This means that also the cost of supplying onshore wind is now at and below the LCOE of the lowest cost new-build combined cycle natural gas plants in the USA.

The lowest wind PPA was achieved in Saudi Arabia in June 2024 at 1.565 c/kWh

RENEWABLE ENERGY DEVELOPMENTS

Onshore Wind - Future technologies

The main factor in decreasing costs is the increasing size of the onshore wind turbines. In 2018 the typical wind turbine was 2.6 MW with a rotor diameter of 110 meters. In 2022 and beyond onshore wind turbines of 5.8 MW with a rotor diameter of 170 meters are anticipated. The higher turbines and larger rotors permit to operate at lower wind speeds thereby increasing the efficiency.

Other improvements that are contemplated are better aerodynamics of the blades, improved composite materials to make blades and better turbine monitoring with artificial intelligence to reduce maintenance costs.

RENEWABLE ENERGY DEVELOPMENTS

Future Onshore Wind Costs

It can be estimated that prior to 2030, onshore wind will be able to produce power in the range of 1.0 – 5.0 cents per kWh, with a probable average LCOE of about 3.2 cents/kWh (2020 $).

WindEurope expects a cost of 3.3 cents/kWh. DOE (US) forecasts are about 3.1 cents/kWh

This means that onshore wind energy will be cheaper than any new build fossil fuel plant in the USA and at the marginal costs of operating coal plants in the USA.

By 2050 onshore wind may be in the range of 0.8 to 4 cents/kWh (2020$), with a probable average of 2.5 cents/kWh.

RENEWABLE ENERGY DEVELOPMENTS

Airloom Device

An entirely new concept for wind energy is a device developed by a Wyoming company called Airloom Energy.

Airloom's 2.5 MW setup uses 25 meter poles to suspend an oval shaped lightweight track, into which 10 meter blades are placed vertically.

As the wind blows, they move around the track.

One standard tractor-trailer can move the entire device to location. It can produce more power on the same amount of land because space between tracks is less than for typical turbines.

Airloom claims that the LCOE will be one third of standard turbines.

RENEWABLE ENERGY DEVELOPMENTS

Offshore Wind – Current Costs

The IRENA information indicates that with respect to offshore wind auctions on a worldwide basis the average costs in 2022 will be 10.8 cents/kWh, with most projects ranging in the 6.0 to 14.0 cents/kWh range. In NW Europe most projects are in the 6.0 to 10.0 cents/kWh range.

The BNEF data base indicates a typical costs of 7.8 cents/kWh for offshore wind in 2020. Lazard rates an average cost of 8.9 cents/kWh.

RENEWABLE ENERGY DEVELOPMENTS

Offshore Wind – Current Costs

Shell offered 5.8 cents/kWh PPA for the offshore Mayflower wind farm off USA.

A recent 15-year PPA for 480 MW between Danske Commodities and Equinor on the Dogger Bank offshore wind was estimated at 4.67 cents/KWh for delivery by 2023.

In July 2022 the UK awarded five wind projects with a PPA of 4.4 cents/kWh.

Typically, one needs to add 1 or 2 cents per kWh for the connection to the shore.

This indicates that offshore wind is now at the lower end of the new-build fossil fuel cost range for coal.

RENEWABLE ENERGY DEVELOPMENTS

Offshore Wind – Projects

-- South Korea has agreed to a massive $ 43 billion project to create 8200 MW of offshore wind off the SW coast.

-- The UK has the very large 3.6 GW Dogger Bank offshore wind farm in development by SSE and Equinor. The project features 227 turbines of 14.7 MW of the GE Halide series.

-- Australia has issued 12 evaluation licenses for 25 GW in the Gippsland Offshore Wind Zone off Victoria.

-- Chile is planning 960 MW floating offshore wind.

-- Shanghai is planning 29.3 GW offshore wind to cover half the demand of the city.

-- Iceland planning 10 GW offshore wind for export to UK.

-- Netherlands issued permits for 4 GW offshore wind.

RENEWABLE ENERGY DEVELOPMENTS

Offshore Wind - Future technologies

The main factor in decreasing costs is the increase in height and rotor size. Offshore turbines are estimated to grow from the current size of about 5 MW with towers over 290 m.

Siemens introduced a 14 MW model. Vestas has now developed the V236-15 MW offshore turbine with a swept area of 43,000 m2 and a production capacity of 80 GWh per year. Its rotor diameter is 236 meter and the cut-in wind speed is 3m/s. It will also introduce the highest onshore wind tower of 199 m by 2025.

A 16 MW turbine has been developed jointly by Goldwind and China Three Gorges Corporation. It is 146 meter high, with a swept area of 50,000 m2.

The Chinese company CSSC announced in early 2023 an 18 MW turbine with a rotor with a diameter of 260 meters.

RENEWABLE ENERGY DEVELOPMENTS

Offshore Wind - Future technologies

GE is developing an 18 MW Haliade-X offshore turbine. The specs have not yet been released but similar size turbines developed in China have a rotor diameter of 260 meters.

The Ming Yang Smart Energy Group is planning a 22 MW turbine with a rotor diameter of more than 310 meters (higher than the Eiffel Tower). They expect to built the prototype by 2024 or 2025.

Sandia National Laboratories has developed "Twistact". This is a fundamentally new rotary electrical contact that eliminates rare earth metals, reduces costs and operates for 30 years without maintenance or replacement.

RENEWABLE ENERGY DEVELOPMENTS

Future Offshore Wind Costs – Fixed to the Seabed

It can be estimated that prior to 2030, offshore wind will be able to produce power in the range of 4.0 – 10.0 cents per kWh, with a probable average LCOE of about 5.0 cents/kWh (2020$). WindEurope is expecting 4.8 cents/kWh. DOE(US) is expecting 5.5 cents/KWh. This applies to offshore wind installations that are fixed to the seabed.

Some analysts expect the upcoming licencing rounds to result in PPAs of 3.5 cents/kWh. This means that offshore wind energy will be cheaper than new coal plants. Some countries such as China, South Korea, Japan, the UK, the Netherlands and Denmark will benefit enormously from offshore wind.

By 2050 offshore wind may be in the range of 3 – 6 cents/kWh (2020$), with an average costs of about 4 cents/kWh

RENEWABLE ENERGY DEVELOPMENTS

Future Offshore Wind Costs – Fixed to the Seabed

A Dutch-German transmission operator TenneT has awarded a 23 billion Euro program to connect 22 GW of offshore wind to the Netherlands and Germany.

The project is based on eleven 2 GW grid connections.

Hitachi and Petrofac, GE and Sembcorp Marine Offshore Platforms, and GE and McDermott will deliver the offshore platforms, onshore substations as well as the HVDC lines.

In total 8 offshore windfarms in the Netherlands and 3 offshore windfarms in Germany will be connected by 2031.

The US BOEM has launched its first offshore lease sale off Louisiana and Texas with a total potential capacity of 3.6 GW.

RENEWABLE ENERGY DEVELOPMENTS

Offshore Wind – Floating Turbines

Instead of fixed to the seabed, floating designs are now being installed for deeper water; 80% of the world oceans is deeper than 60 meters.

Offshore wind turbines typically have a higher capacity factor due to winds more prevailing offshore. For instance, the typical wind power density is more than 1300 W/m2 deep offshore the Shetland Islands, compared to 900 W/m2 in the shallow North Sea and 500 W/m2 onshore Denmark and the Netherlands.

Using its offshore experience Equinor is investing significantly in floating offshore turbines. The first floating wind farm is the Hywind project offshore Scotland. WindEurope expects floating offshore wind to costs about 6.4 cents/kWh by 2030 and DOE(US) about 8 cents/kWh. By 2050 it is expected to be 5 cents/kWh.

RENEWABLE ENERGY DEVELOPMENTS

Offshore Wind – Floating Turbines

The California Energy Commission has set a goal of 3000 to 5000 MW of offshore wind by 2030 and 25,000 MW by 2045.

Due to the water depth in the Pacific this would have to be largely floating offshore wind.

The Biden administration targets in total 30 GW of offshore wind for the US. In total five areas are being auctioned off California.

Equinor and Posco International will built the largest floating offshore wind farm off Ulsan, South Korea, consisting of 50 turbines of 15 MW each for a total of 750 MW.

RENEWABLE ENERGY DEVELOPMENTS

Offshore Wind –Floating Turbines

-- A Boston startup called T-Omega Wind is working on a pyramid-based concept based on four iron tubes meeting at the tip of the pyramid, where the wind turbines is located.

-- The have developed a 27-foot prototype for testing.

-- The nacelle, where the power is generated, moves with the wind.

-- A 10 MW turbine with a 180-meter rotor would be on top of a 119-meter pyramid with 70-meter sides.

-- They hope to bring a full-scale turbine to market by 2028.

RENEWABLE ENERGY DEVELOPMENTS

Offshore Wind – Vertical Floating Turbines

-- A Norwegian Company called World Wide Wind Tech S.A. has designed a vertical floating wind turbine.They have to counter-rotating turbines, one on top and one on the bottom. It is tilted with the winds (similar to sailboats). The generator is below the water level and act as ballast under the floater.It has a reduced wake and therefore permits greater density of turbines.

The goal is to create 400 meter high 40 MW turbines that would cost less than $ 0.05 per KWh and install the first turbine by 2029.

-- A Swedish company SeaTwirl is also developing a horizontal floating design aiming for 30 MW turbines also with a future anticipated cost of $ 0.05 per kWh. A 1 MW test turbine is expected to be commissioned offshore Norway in 2023.

RENEWABLE ENERGY DEVELOPMENTS

Offshore Wind – Floating Box with Small Turbines

Another Norwegian Company called Wind Catching Systems AS has developed an upright open box (in excess of 324 meters high and wide) in which 126 smaller wind turbines are fixed with a rotor size of only 30 meter.

This makes more efficient use of the available wind passing through the box and can accommodate higher wind speeds.

They claim that one box can generate as much power as 5 regular vertical axis wind turbines of 15 MW each and could therefore deliver power at lower costs.

Wind Catching Systems has now received certification for their system.

General Motors Ventures is investing in the development.

RENEWABLE ENERGY DEVELOPMENTS

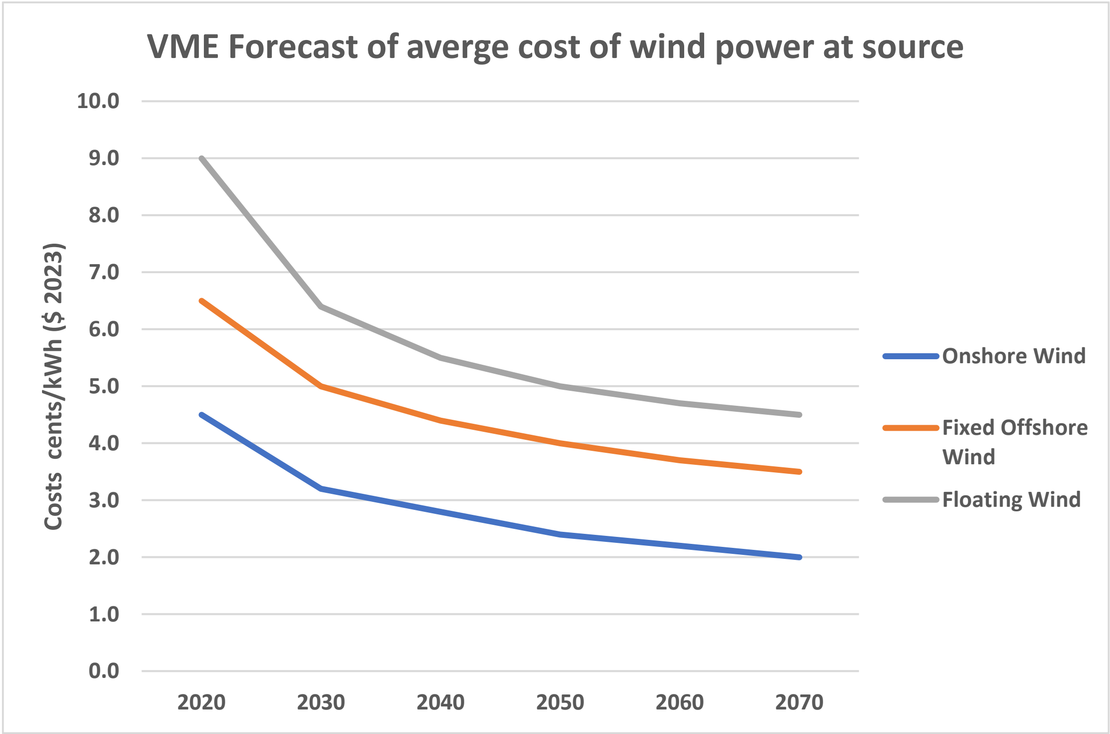
Wind – Future Costs

VME FUTURE WIND ENERGY COSTS (2023 $)							
		2020	2030	2040	2050	2060	2070
Onshore Wind	cents/kWh	4.5	3.2	2.8	2.4	2.2	2.0
Fixed Offshore Wind	cents/kWh	6.5	5.0	4.4	4.0	3.7	3.5
Floating Wind	cents/kWh	9.0	6.4	5.6	5.0	4.7	4.5

Costs of wind generation is expected to continue to drop. However, in general no major technological breakthroughs are expected. Cost reduction will be achieved through larger volume production, larger turbines and increasingly better materials

RENEWABLE ENERGY DEVELOPMENTS

Wind – Future Costs



The graph shows the forecasts made in the previous slide.

RENEWABLE ENERGY DEVELOPMENTS

Wind Power Research – Non-Blade Technologies

It should be noted that entirely different wind energy concepts are also in the research stage.

The Vortex Bladeless Turbine is a vertical pillar that wobbles and generates wind energy on a much simpler basis, potentially cutting costs for small applications.

Delft University in the Netherlands has developed a Solid-State Wind Energy Converter, with no moving parts at all, called EWICON. In this case air is ionized with a high voltage current that creates a positive charge when wind blows this air.

RENEWABLE ENERGY DEVELOPMENTS

Wind Power Research – Non-Blade Technologies

It should be noted that entirely different wind energy concepts are also in the research stage or at the verge of being commercialized.

-- The Vortex Bladeless Turbine is a vertical pillar that wobbles and generates wind energy on a much simpler basis, potentially cutting costs for small applications.

-- Delft University in the Netherlands has developed a Solid-State Wind Energy Converter, with no moving parts at all, called EWICON. In this case air is ionized with a high voltage current that creates a positive charge when wind blows this air.

-- Aeromine is promoting a fixed system which sucks air passed a small propellor. It is designed to function well on the roofs of buildings.

RENEWABLE ENERGY DEVELOPMENTS

Wind Power – Wind Turbine Wall

John Doucet of Airiva Wind Turbines has developed a "wind turbine wall" consisting of 2-meter-tall vertical blades with a helix shape rather than propellor style.

A set of 8 encased in a frame could deliver 2200 kWh per year.

Its main asset is that it has a visual appeal and integrates well in buildings. Wall segments can be joined in long walls.

It is intended to be in commercial operation by 2025.

RENEWABLE ENERGY DEVELOPMENTS

Wind Generation

Based on IEA data the 2020 world wind generation was 1596 TWh.

The following chart shows the distribution

Wind Generation (TWh)			`
	Total	Wind	(%)
WORLD	**26762**	**1596**	**6.0%**
North America	**5221**	**391**	**7.5%**
United States	4243	340	8.0%
Central and South America	**1277**	**78**	**6.1%**
Brazil	605	57	9.4%
Europe	**3962**	**517**	**13.0%**
European Union	2757	398	14.4%
Africa	**827**	**17**	**2.1%**
Middle East	**1189**	**2**	**0.2%**
Eurasia	**1335**	**2**	**0.1%**
Russia	1057	1	0.1%
Asia Pacific	**12961**	**588**	**4.5%**
China	7787	471	6.0%
India	1609	68	4.2%
Japan	1003	8	0.8%
South East Asia	1111	7	0.6%

RENEWABLE ENERGY DEVELOPMENTS

Offshore Wind and Floating Solar

An option that is receiving considerable attention is the combination of offshore wind and floating solar located among the wind generators.

This creates an optimal load configuration.

On sunny days with little wind, the solar generation is strong, while on stormy days with little sunshine the wind generation is strong, creating an overall more sustained renewable power production.

RENEWABLE ENERGY DEVELOPMENTS

Concentrated Solar Power – Current Costs

Concentrated Solar Power is based on systems whereby molten salt or other materials are heated with solar energy from solar mirrors during the day in order to deliver power on a continuous basis. For 2018 IRENA quoted a LCOE range of 10 to 28 cents/kWh, with an average of 18.5 cents/kWh.

For 2022 auction bids have been received of 7.5cents/kWh

Lazard lists US costs for 2019 at 12.6 – 15.6 cents/kWh.

This indicates that CSP used to be more expensive than fossil fuel generation but that improved conditions are bringing these costs down.

RENEWABLE ENERGY DEVELOPMENTS

Concentrated Solar Power - Future technologies

The main factor in decreasing costs does not relate to new technologies but to more efficient supply chains and new projects moving to areas with a higher quality solar radiation.

However, other important factors are improvements in mirror orientation and improvements in heat storage. Storage has improved from about 4 hours to 8 hours.

At this time there is only a limited number of projects being committed and therefore there is no clear trend in indications of important technical factors.

RENEWABLE ENERGY DEVELOPMENTS

Concentrated Solar Power - Future technologies

An interesting development in CSP is researched at the US Sandia Laboratories, supported by DOE.

The concept is a Falling Particle Receiver ("FPR"). Ceramic bauxite particles are at the top of the tower and can be heated to very high temperatures of 800 degrees Celsius or more. Once heated the particles fall in a collector and can produce electricity when needed. Once the heat in the particles has been used, the particles are moved back to the top of the tower.

Very high temperatures permits more efficient electricity production.

Australia's CSIRO uses a similar system which also achieved more than 800 degrees Celsius. The new technology is cost effective and may have a payout period of 5 years.

RENEWABLE ENERGY DEVELOPMENTS

Future Concentrated Solar Power Costs

It can be estimated that prior to 2030, the cost of CSP will be in the range of 5.0 to 14.0 cents/kWh, with may be an average costs of 7 cents/kWh (2020$). Average costs by 2050 may be 5.5 cents/kWh (2020$). However, these levels still have a considerable possible margin of error.

In general, it seems that CSP plants may be developed competitive with new fossil fuel plants. This would be important since the advantage of CSP is obviously that it provides continuous electricity all day rather than depending on solar hours. Morocco has embarked on large CSP projects.

Dubai is expanding its CSP project with 950 MW, the largest CSP project in the world.

RENEWABLE ENERGY DEVELOPMENTS

Solar Heat

Apart from using solar energy to produce electricity, it can be used directly to produce steam or heat.

For instance, in Oman the national oil joint venture company PDO produces steam directly from solar energy in order to enhance the recovery of heavy oil.

Heliogen a start up company in the US has developed an artificial intelligence-based concept to focus hundreds or mirrors on a single small point, producing industrial heat well over 1500 degrees Celsius. This can be used for a variety of industrial purposes and possibly for the direct production of hydrogen through thermochemical processes. Full thermolysis of water takes place at 2200 degrees Celsius.

RENEWABLE ENERGY DEVELOPMENTS

Hydropower

The traditional form of renewable energy is hydropower. Current hydropower production is about 4000 TWh/year. Total world economic hydropower potential is about 9000 TWh/year. It is for this reason that it is expected that hydropower will continue to make an important contribution to new electricity generation.

There is still a number of countries with large (more than 100 TWh/year) economic hydropower resources of which only a small fraction has been developed. These countries are Cameroon, DRC, Ethiopia, Ecuador and Peru. (100 TWh = 100,000,000,000 kWh)

Other countries with still large remaining economic hydropower resources are Angola, Madagascar, China, Kyrgyzstan, Vietnam, Norway, Russia, Iceland, Canada, Bolivia, Brazil, Chile and Colombia.

RENEWABLE ENERGY DEVELOPMENTS

Hydropower

The 2023 World Hydropower Outlook by the International Hydropower Association establishes that the total world capacity is 1,412 GW of which 182 GW is pumped storage hydropower.

To reach the 2050 objectives investments in hydropower have to double to a total of $ 130 billion per year.

RENEWABLE ENERGY DEVELOPMENTS

Hydropower

Hydropower will also continue to play an important role in North America.

A large project that was approved in 2022 is the 1250 MW Hydropower electricity grid link of Hydro-Quebec to supply New York.

Another large project is a $ 5 billion hydropower deal managed by the French EDF in Mozambique. It will generate 1500 MW of power in the northern province of Tete with a powerline to the capital Maputo.

RENEWABLE ENERGY DEVELOPMENTS

Hydropower

The LCOE of hydropower is rather site specific and large projects typically have lower costs than small projects.

However, the IRENA estimate of the world average LCOE is 4.7 cents/kWh. The typical range is 2.5 – 12.0 cents/kWh. Although costs for some countries in Europe are well over these levels.

Future costs of hydropower depend largely on the location. No new technologies are contemplated that could reduce costs. However, it is contemplated that hydropower costs of economic projects will remain well in the range of fossil fuel-based power of 4.4 to 15.2 cents/KWh.

Increasingly important is the role of hydropower in pumped storage. Current round-trip efficiency is about 70%. It is anticipated that further R&D can still improve this to 80%.

RENEWABLE ENERGY DEVELOPMENTS

Geothermal Power and Heat

Geothermal Energy can be used for power generation and direct heating for agricultural, industrial and other purposes.

Total world production (not including geothermal heat pumps) is about 75 TWh for power as well as 75 TWh for heat.

The main countries using geothermal power are: the United States, Philippines, Indonesia, Mexico, New Zealand, Italy, Iceland, Turkey, Kenya and Japan.

The main countries using geothermal heat are: China, Turkey, Iceland, Japan, Hungary, the United States and New Zealand.

RENEWABLE ENERGY DEVELOPMENTS

Geothermal Power

The LCOE of geothermal power is rather site specific.

However, the IRENA estimate of the world average LCOE is 7.2 cents/kWh for new plants. The typical range is 6.0 – 14.0 cents/kWh. Costs have actually gone up over the last decade. The typical costs in the United States in 2015 was about 3.9 cents/kWh. The NREL databank indicates in 2021 PPAs of about 5.5 cents/kWh.

Future costs of geothermal power are unlikely going to be competitive with wind and solar PV and therefore the growth of geothermal power can be estimated to be modest.

RENEWABLE ENERGY DEVELOPMENTS

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RENEWABLE ENERGY DEVELOPMENTS

Geothermal Power

-- The Deep Earth Energy Production Co (DEEP) in Saskatchewan has started to construct a geothermal project for power generation. The construction will start with 5 MW to be followed up by 20 MW under a PPA with SaskPower.

Production and injection wells are planned for a depth of 3.5 km with a horizontal leg of 3 km.

First power production is planned for mid 2024.

-- Poland is drilling the deepest geothermal well at 7km deep, the Banska PGP-4 site at Szaflary. The goal is to reach temperatures of 150 degrees Celsius.

RENEWABLE ENERGY DEVELOPMENTS

Geothermal Power - Supercritical

When water is heated beyond 373 degrees Celsius and 220 bars of pressure, it enters a supercritical stage that holds 4 to 10 times more energy per unit mass than regular steam.

This is still in the research stage and requires ultra-deep drilling.

Ultra-deep drilling by GA Drilling based on extremely hot drilling PLASMABIT technology could liberate steam at 10 km deep.

RENEWABLE ENERGY DEVELOPMENTS

Geothermal Power – Quaise Energy

Quaise Energy is working on an entirely new drilling technology which vaporizes boreholes through rock, with a goal to reach 20 km deep at 500 degrees Celsius temperatures.

The vaporization of the bore hole will be based on an MIT process which in turn is based on processes used in fusion technology.

Ultra-deep geothermal could be developed essentially anywhere on the planet.

This will enable Quaise Energy to take over coal fired power plants and simply supply the plant with geothermal steam instead of steam generated by coal.

RENEWABLE ENERGY DEVELOPMENTS

Geothermal District Heating

Geothermal district heating is in principle a simple process and can be done anywhere in the world.

It consists of drilling from a single platform two deviated wells to a depth sufficient to reach high temperatures, which could be between 2000 and 3500 meter. One well is a producer of hot water bringing this water to a heat exchanger, the resulting cold water is reinjected back in the ground. The heat is piped through the community. Systems could be in the 0.5 to 50 MW range.

Geothermal district heating systems are increasingly applied in the world. They are most economic in areas with high heat flows (such as volcanic areas) and in cities with dense population.

However, the Leeuwarden Project in the Netherlands is also economic and will initially supply heat to large customers.

RENEWABLE ENERGY DEVELOPMENTS

Geothermal for Agriculture

Horticulture companies in IJsselmuiden in the Netherlands have drilled two geothermal wells to 1950 meters. This produces water with a temperature of 73 degrees Celsius for the use in greenhouses.

This will save them 315 million cubic feet of natural gas per year. A reduction of 70 – 90% and a considerable financial saving.

RENEWABLE ENERGY DEVELOPMENTS

Tidal Energy

Tidal energy consists of two type of projects: tidal range projects and tidal stream projects.

Tidal range projects make use of high and low tides to fill and empty a basin. The cheapest project in the world is the 254 MW Sihwa Lake project in South Korea, which costs about 3 cents/kWh. Other tidal range projects are much more expensive.

Tidal stream projects make use of the tidal current to move the blades of a turbine. A large number of turbine designs is being proposed, but it seems that the LCOE is over 20 cents/kWh. Future costs may be as low as 10 cents/KWh. Therefore, these projects may not make a significant contribution to world renewable energy generation. The MeyGen project is currently operating off the north coast of Scotland with an estimated cost of 12.3 cents/kWh.

RENEWABLE ENERGY DEVELOPMENTS

Tidal Energy

Tidal energy in the Faroe Islands is generated with the so-called tidal kite. The tidal kite is moored at the bottom of the sea but "flies" through the tidal current.

Marine energy developer Minesto has carried out the initial tests. It now hopes to increase the capacity in Vestmannasund to 1.4 MW.

It anticipates that in total 20 to 40 MW can be generated this way with the objective to supply 40% of the energy requirements of the Faroe Islands, permitting the country to reach 100% renewable energy by 2030.

The University of Edinburg has developed cheaper lighter blades that could make tidal energy more economic according to Dr. Eddie McCarthy.

RENEWABLE ENERGY DEVELOPMENTS

Wave Energy

There is a large number of small wave power projects in operation or planned.

A number of other projects are in operation in the UK, Portugal, Australia. The Bombora project in Australia is anticipated to have an LCOE of over 20 cents/kWh.

The largest wave power project is by Swedish Eco Wave Power aiming for 77 MW in Ordu, Turkey.

The Australian company Wave Swell Energy believes that their design when scaled up to 100 MW could deliver energy at 9 cents per kWh.

Wave power could be economic for some nice applications where solar, or wind have environmental or other construction problems.

CalWave of California has demonstrated a wave generator with 99% uptime and no maintenance for 10 month.

An interesting use of wave energy is for desalinization. Oneka Technologies is developing a concept that only uses wave energy to produce fresh water.

RENEWABLE ENERGY DEVELOPMENTS

Wave Energy

Hawaii has installed the first grid-scale wave energy generator of 1.25 MW.

It is an OE-35 device developed by Ocean Energy. It is located off Oahu.

It is based on turbines moving based on compressed air created by the waves.

RENEWABLE ENERGY DEVELOPMENTS

Ocean Current Energy

The Japanese company IHI has successfully completed an ocean current test. This was done in the strong and constant Kuroshio Current close to Japan. The instrument, called "Kairyu", floats in the current moored to the bottom at about 50 meters deep. It was a 100 kW current turbine.

The current flows at 1 – 2 meters/second.

The company is now preparing a commercial scale 2 MW project.

RENEWABLE ENERGY DEVELOPMENTS

Biogas

Biogas is produced by the breakdown of organic matter in the absence of oxygen. The organic materials can be from landfills, agricultural waste, manure, green waste, municipal waste, food waste or sewage. The resulting gas is largely a mixture of 50-70% methane and 25-40% CO_2, as well as other gasses, such as nitrogen and H_2S and contains moisture and siloxanes.

Production can be done in an anaerobic digester. The biogas can used directly to produce heat or electricity. The liquid residue remaining, the digestate, is a good fertilizer. The world biogas electricity capacity is 18 GW. United States has 2200 operating biogas systems. A side-benefit of producing biogas is that otherwise some methane will result from the regular decomposition, and this will escape in the atmosphere and is a potent greenhouse gas.

RENEWABLE ENERGY DEVELOPMENTS

Biomethane

Biogas can be cleaned up to produce biomethane of pipeline natural gas quality.

This is in fact, renewable natural gas ("RNG"). Currently, the renewable natural gas production is about 0.1% of the total natural gas production. However, there is potential for a much larger production. The IEA estimates that world production can be increased by a factor 20. For the moment RNG costs are high but may be reduced over time.

TotalEnergies signed a contract with Vanguard to built RNG projects in the United States for a yearly capacity of 2.5 billion cuft. Plans are to expand to 15 Bcf per year.

RENEWABLE ENERGY DEVELOPMENTS

Bio-LNG

Ships can now bunker bio-LNG at about 70 ports world wide, including Singapore, Rotterdam and the US East Coast.

About 355 LNG-fueled ships can use bio-LNG as drop-in fuel without modification.

Annual production of biomethane is now about 30 million tons, which is 10% of the shipping requirements.

Bio-LNG reduces greenhouse gas emissions by 80% compared to diesel fuel. Depending how it is produced it can even be NetZero or carbon-negative.

RENEWABLE ENERGY DEVELOPMENTS

Green Methanol

The first cargo ship that is run on green methanol is now operating.

The methanol is produced from methane recovered from landfills.

Maersk is operating the ship and has ordered 25 more of these cargo vessels.

This is part of the plan of Maersk to decarbonize by 2040.

The green methanol was delivered by the Dutch company OCI Global.

RENEWABLE ENERGY DEVELOPMENTS

Biochar

Biochar produced from wood or other plant material is still widely used in developing countries as renewable fuel.

Currently also other uses are contemplated.

Researchers at the RMIT University of Australia are converting solid organic waste into biochar through a process called PYROCO, which is really a pyrolysis process. Pyrolysis is high temperature heating without oxygen. The biochar can be used as fuel.

This prevents this waste to end up in landfills and decompose with the resulting CO_2 emissions.

RENEWABLE ENERGY DEVELOPMENTS

Biomass to Power

The production of electricity from biomass can be based on a very wide range of biomass sources. Important sources are bagasse, landfill gas, wood chips, rice husks, wood waste, agricultural waste, municipal waste, straw and black liquor (a byproduct of the pulp and paper industry). Based on IRENA data, costs depend largely of the costs of the biomass. Significant production occurs in China and India, but also in Europe and North America. Typical costs are between 4 and 15 cents/kWh, with average costs in the range of 6 to 8 cents/kWh. A recent auction in Brazil resulted in 6.6 cents/kWh. No technical breakthroughs are contemplated.

Biomass to power will make an ongoing contribution to renewable energy. Together with carbon capture and storage this is a way for a carbon negative operation as will be discussed under BECCS policies.

RENEWABLE ENERGY DEVELOPMENTS

Biomass to Power

An interesting project in this regard is the use of cocoa husks for power generation.

Ivory Coast is the worlds largest exporter or cocoa. The Ivorian company SODEN is constructing a power plant that will use the husks of the cocoa to fuel a power plant in Divo, which will be able to deliver between 46 and 70 MW of power per year. The cost of the plant is $ 244 million. The plan is to built 9 of these plants across the country. It will deliver renewable energy and improve the economics of cocoa production.

RENEWABLE ENERGY DEVELOPMENTS

Current Biofuels Production

The world biofuels production in 2018 was 2,616,000 bopd. This consist largely of biogasoline at 1,890,000 bopd and biodiesel at 702,000 bopd.

The United States is the leading producer with 1,190,000 bopd of biogasoline and 138,000 bopd of biodiesel. The biogasoline is largely made of corn and biodiesel of soybeans. There are more than 200 fuel ethanol production plants in the US.

Brazil is the second largest producer, with a total production of 693,000 bopd, largely consisting of biogasoline from sugarcane and also some biodiesel from soybeans.

Germany produces large volumes of biodiesel from rapeseed and cooking oil. Other large producers are Argentina and China. Thailand is a large gasohol producer based on casava.

RENEWABLE ENERGY DEVELOPMENTS

Advanced Biofuels

Most of current biofuels are made from sugars or vegetable oils which compete with the production of food. From a renewable energy perspective there is no future for such biofuels, since they cannot be produced on a large scale without negatively impacting the world food production.

Therefore, the future of biofuels for energy purposes has to be based on advanced biofuels. These are biofuels, that are produced from non-food crops that are grown on marginal land unsuitable for food production. It includes also biofuels based on plant materials and animal waste, as well as biofuels based on algae grown in special containers on desert type land.

RENEWABLE ENERGY DEVELOPMENTS

Advanced Biofuels

There is an extremely large number of ways of making advanced biofuels.

The bio feedstocks include: a very wide variety of energy crops, municipal waste, green waste (from forests, parks or gardens), algae, aquatic bacteria, black liquor, etc.

Processes to make the biofuels include: gasification, pyrolysis, torrefaction, hydrothermal liquefaction and a variety of biochemical routes.

Biofuels can than be made from: syngas using catalysis, syngas using Fischer-Tropsch, biocatalysis or a variety of other processes.

In general, the overall efficiency of reducing CO2 is that the biofuels have a 60- 80% efficiency compared to the corresponding fossil fuels emissions.

RENEWABLE ENERGY DEVELOPMENTS

Advanced Bio Jet Fuel

Probably the most important biofuel from a renewable energy point of view is bio jet fuel, since no other form of renewable energy would provide a comprehensive solution for air transportation.

NREL evaluated 14 different technologies of making bio jet fuel. A large number of airline companies already use such bio jet fuels on a small scale.

Costs of bio jet fuels is still high; in the range of $ 110 - $250/bbl. Costs will be reduced in the future through the intensive research taking place. Nevertheless, there are no clear pathways resulting in possible substantial cost reductions. It is for this reason that in this presentation we forecast only a limited use of bio jet fuel by 2050.

RENEWABLE ENERGY DEVELOPMENTS

Advanced Bio Jet Fuel

The Gunvor Group with VARO Energy will build a 350Kt per year facility for sustainable aviation fuel production in Rotterdam.

RENEWABLE ENERGY DEVELOPMENTS

Advanced Bio Jet Fuel - SAF

-- Nevertheless Qantas, Airbus and the Queensland government are teaming up to create a biofuel refinery to produce jetfuel from agricultural byproducts primarily sugarcane.

The facility is being constructed by LanzaJet Australia and will produce 100 million liters of Sustainable Aviation Fuel (SAF) per year.

-- A Gulfstream G700 just achieved a speed record of 0.89 Mach flying from Savannah, Georgia, to Tokyo in 13 hours using only SAF.

-- Boeing and Airbus have both confirmed that by 2030 all new aircraft will be compatible with 100% SAF. SAF is the ideal fuel for long haul routes.

RENEWABLE ENERGY DEVELOPMENTS

Advanced Bio Jet Fuel – Kelp Farming

An interesting option for producing advanced bio jet fuel is kelp farming.

Marine BioEnergy is developing kelp farming near Santa Cataline Island off California. Kelp uses a huge amount of CO_2 to grow. The growth of kelp can be accelerated with booms to which kelp is attached that can be moved to various depth for optimal growing.

The advantage of kelp farming is that it does not replace agricultural land. Only 0.5% of the world oceans can grow all jet fuel for aviation and diesel for long distance transport.

Large scale farming may reduce costs.

RENEWABLE ENERGY DEVELOPMENTS

Anti-Solar

Research is currently going on with respect to so-called anti-solar panels that operate at night.

A team of Stanford University in Palo Alto has developed a thermo-electric generator device that operates on the thermal heat being radiated outwards from the earth during the night.

It operates with a passive cooling mechanism that maintains a temperature difference between the two sides of the panel, which in turn generates electricity.

If this could be commercialized it would be an interesting component of the renewable energy picture.

RENEWABLE ENERGY DEVELOPMENTS

Ocean Thermal Energy Conversion (OTEC)

A UK company called Global OTEC is developing a 1.5 MW process in Sao Tome and Principe, based on OTEC, called Dominique.

OTEC uses heat from ocean surface water, heat fluids with a low boiling point and uses the steam to generate electricity.

This is 24/7 renewable energy.

There are currently only two small pilot project in Hawaii and Japan at a small 100 kW.

It is expensive due to long pipes from the seabed to the surface.

The project would only use a 750-meter pipe.

Dominique could play a role in other island nations that currently rely on diesel generation.

RENEWABLE ENERGY DEVELOPMENTS

Humidity

Air contains enormous amounts of electricity in water droplets, as is well know during lightning. The question is how to harvest it.

Mr. Jun Yao of the University of Massachusetts Amherst has shown that electricity can be generated with ultra thin nanowires of less than 100 nanometers (less then a thousands of the width of a human hair). This is the “free path” of water molecules suspended in air with loaded electricity.

This harvest the water molecules which move from the upper to the lower part of the wire. However, the concentration becomes stronger at the upper part. This creates a natural battery.

By stacking thousands of nanowires, kilowatt-level power can be generated anywhere on earth on a 24/7 basis.

RENEWABLE ENERGY DEVELOPMENTS

AISEG

The AI Smart Electromagnetic Generator (AISEG) is developed by the South Korea SEMP Institute under Woohee Choi.

The concept is to trick with AI a generator into accepting positive and negative charges AI generated.

This will automatically create a generator to produce electricity without fuel or emissions.

It was demonstrated at the COP28 convention.

It could potentially have wide applications.

RENEWABLE ENERGY DEVELOPMENTS

Hybrid Projects

Hybrid projects deal with the irregularity of the availability of solar and wind and make 100% renewable energy viable and economic.

Two types of hybrid projects are gaining interest:

-- floating solar and hydro, whereby solar panels floating on a hydro reservoir optimize low cost solar with reliable hydro, and

-- solar, wind and energy storage, whereby solar and wind are optimized, and energy is stored during excess renewable production and used when required to be discussed under "Renewables and Storage".

RENEWABLE ENERGY DEVELOPMENTS

Hybrid Projects

-- The Electricity Company of Thailand (EGAT) is currently operating a 45 MW solar-hydro facility in the Sirindhorn Dam. The solar panels only occupy 1% of the water reservoir.

RENEWABLE ENERGY DEVELOPMENTS

Solar plus Wind - Current Costs

Hybrid projects consisting of solar plus wind generation also receive increased attention.

Tata Power in India has signed a 25-year PPA for a 510 MW project consisting of 170 MW of solar and 340 MW of wind.

The PPA price is 3.7 cents/KWh.

RENEWABLE ENERGY DEVELOPMENTS

India-Solar-Wind

-- NTPC Renewable Energy, Green Infra Wind Energy, and Juniper Green Energy have emerged as winners of the Solar Energy Corp of India (SECI) 2 GW wind-solar hydrid power bid round.

The are willing enter into a 25-year PPA for 900 MW with a price of 3.8 cents/KWh.

It will be developed on a Build Own Operate basis.

-- The largest renewable energy project is being launched in India. It is the Khavda Renewable Energy Park in Gujarat, to be done by Adani Green Energy Limited. It will be a 30 GW project covering 726 square kilometer costing at least $ 2.26 billion and consist of solar and wind.

RENEWABLE ENERGY DEVELOPMENTS

Wind, Solar and Tidal Energy

A study done by Dr. Danny Coles of Plymouth University emphasizes that tidal energy is a very reliable source of energy and that the combination of wind, solar and tidal provides a very secure renewable energy sypply.

Adding tidal energy to the wind plus solar combination lowers the overall costs of the energy supplies.

RENEWABLE ENERGY DEVELOPMENTS

Renewable Energy for Power Generation - Conclusions

The framework for the economic development of renewable energy for power generation will be the LCOE of competing fossil fuels. It is assumed that this range in constant 2020 $ will remain about 4.4 – 15.2 cents/KWh for the coming decade.

Before 2030, the cost of Solar PV is expected to be on average 2.5 cents/kWh and onshore wind 3.2 cents/kWh, well below this range.

The cost of offshore wind is expected to be 5.0 cents/kWh and concentrated solar power 7.0 cents/kWh which is at the lower end of this range. Economic hydropower will also be at the lower end of this range.

RENEWABLE ENERGY DEVELOPMENTS

Renewable Energy for Power Generation - Conclusions

The current extremely high natural gas and energy prices in Europe and Asia have created unusually attractive conditions for renewables and energy storage. Spot prices in Europe during August 2022 of 400 Euro/MWh would create payback times of less than a year for such projects. However, even at much lower prices, such at 70 Euro/MWh the payback time would be less than a decade. This is an enormous impetus to develop renewables and storage.

RENEWABLE ENERGY DEVELOPMENTS

Renewable Energy for Power Generation - Conclusions

The expected low cost of renewable energy, will be a significant competitive challenge for electricity generation based on coal and natural gas during the next decade. Renewable power generation will rapidly expand as percentage of the total generation.

However, what if there is no sun light and no wind? Natural gas can be expected to remain an important component of the energy mix during the next decade(s) in order to maintain reliable power generation.

The role of natural gas will remain until economic forms of energy storage or energy will replace the need for natural gas. Two important developments will be evaluated: energy storage and hydrogen.

NUCLEAR ENERGY

Growth of Nuclear Energy

Nuclear energy is also a worthwhile contributor to deal with climate change.

The IEA Forecast is that nuclear energy production will continue to increase.

NUCLEAR ENERGY

Small Modular Reactors

It is likely that Small Modular Reactors (SMR) will play an increasing role in providing nuclear energy. SMRs generate between 10 and 300 MW of power and can be built in factory conditions rather than on location. The IEA estimates that by 2030 about 100 SMRs could be operating.

SMRs can be used in smaller grids, such as rural grids or industrial applications. In fact, Canadian oil sands producers are looking at SMRs to produce heat for oil production.

Seaborg Technologies (Denmark) views the possibility of floating barges with nuclear power stations that can be easily produced and installed.

Costs maybe reduced by 25% compared to regular nuclear power.

NUCLEAR ENERGY

Small Modular Reactors

The US Nuclear Regulatory Commission of the US has certified the design of the NuScale Power small nuclear reactor (SMR).

The design is an advanced light water SMR, with each power module capable of generating 50 MW.

It is anticipated to become operational in Utah in 2029.

NUCLEAR ENERGY

Nuclear Fusion

Nuclear fusion is based on two hydrogen isotopes Deuterium and Tritium, which when fused form Helium and release a tremendous amount of energy. This is similar to the process that takes place in the sun.

ITER, the largest world fusion project will commence assembly in July 2020. The first super hot plasma is expected within 5 years.

In principle, this is a source of limitless generation of electricity.

TEA Technologies is of the view that their boron based fusion reactor could be commercially operational in the UK in the middle 2030s.

NUCLEAR ENERGY

Nuclear Fusion

A breakthrough has been reported in 2022 with respect to nuclear fusion. The US National Ignition Facility in California achieved the production of more energy than was used to generate the nuclear fusion with shooting high powered lasers at a fuel pellet. It directed 2.05 MJ at the target resulting in an output of 3.15 MJ

However, whether nuclear fusion can be economic compared to future renewable energy costs remains to be seen.

It is anticipated that as of 2050 the world will already have limitless, clean and cheap energy in the form of solar, onshore and offshore wind and low-cost hydrogen.

ENERGY STORAGE

Energy Storage

In this part of the presentation, we will look at the future of energy storage. Two issues will be reviewed:

-- the cost of batteries, and

-- the cost of utility scale storage systems. These systems include apart from the batteries, the costs of the inverter(s) and cost for connection and construction, including engineering.

The costs are often expressed in $/MWh. For instance, a 60 MW storage system could deliver electricity for 4 hours. This means that the total capacity is 240 MWh. A 240 MW system that delivers power for 1 hour is also 240 MWh. However, the costs of the system will be higher because large inverters and connection systems are required. The Levellized Costs of Storage ("LCOS") are determined based on a capital and operating costs over time.

ENERGY STORAGE

Energy Storage-Overview

Energy storage will be discussed in the following sequence:

- **Electrochemical Storage (Batteries)**
- **Other Energy Storage**

ENERGY STORAGE

Energy Storage-Overview

-- Batteries are batteries of two types:

.. Classic batteries, which can be sub-classified as:

-- lithium-ion based batteries, such as manganese oxide, iron-phosphate, nickel-manganese-cobalt-oxide, and various other varieties and

-- other classic batteries, also of a large variety of types such as the original lead acid batteries, sodium-sulfur, and nickel-cadmium, and

.. Flow batteries, which are operate similar to batteries but are based on liquids (or gas) stored in two separate tanks with ions passing through a membrane. The Vanadium Redox flow batteries are used on a large scale and have a lifetime much longer than regular batteries.

ENERGY STORAGE

Energy Storage-Overview

There is a huge variety of other energy storage systems:

-- Chemical - Hydrogen, ammonia, methanol could be stored for long periods and used for power generation when required.

-- Mechanical – Pumped hydro storage has been used traditionally and is still important. Other methods are gravity systems, flywheels, compressed air, etc.

-- Electrical – Such as supercapacitors, consisting of two carbon-based electrodes with an insulating material in between.

-- Thermal – Such as heat storage in molten salt or liquid air storage.

-- Geothermal – Fervo Energy plans to use Enhanced Geothermal Systems to store heat produced by solar and wind when in excess and produce the heat when needed for electricity or heat.

ENERGY STORAGE

Li-Batteries - How do Lithium-ion batteries work?

A lithium-ion battery consist of an anode, cathode and electrolyte.

The anode (negative) consist primarily of graphite (a variation of carbon) or other material.

The cathode (positive) consists of a metal oxide, which could be cobalt-oxide, lithium-iron-phosphate, lithium-manganese-oxide or other materials.

The electrolyte is a liquid, gel or solid permitting the movement of positively charged lithium-ions.

There is a semipermeable barrier to prevent that the ions move completely freely though the electrolyte and clogging the electrodes.

ENERGY STORAGE

Li-Batteries - How do Lithium-ion batteries work?

During discharging electrons travel from the negative to the positive electrode through the electric wire, at the same time the anode releases positively charged ions in the electrolyte. This process is called oxidation.

At the same time at the positive electrode the negatively charged electrons are received and they are being matched by pulling positively charge lithium-ions from the electrolyte. This process is called reduction.

In total a redox reaction.

When charging the battery the process is reversed.

ENERGY STORAGE

Li-Batteries - Types

Following are the types of Lithium-ion based batteries:

- **Li-Cobalt-Oxide**
- **Li-Manganese-Oxide**
- **Li-Nickel-Manganese-Cobalt-Oxide**
- **Li-Nickel-Cobalt-Manganese-Aluminum-Oxide**
- **Li-Iron-Phosphate**
- **Li-Sulfur**
- **Li-Air**
- **Others**

ENERGY STORAGE

Energy Storage – How do Lithium-ion batteries work?

The following reactions take place in a lithium-cobalt-oxide battery:

At the positive electrode (cathode):

CoO2 + Li (positive) + electron (negative) <===> LiCoO2

At the negative electrode (anode):

LiC6 <===> C6 + Li(positive) + electron (negative)

In this last formula when discharging - electrons are created and graphite remains, when charging LiC6 is being formed.

In total the formula is:

LiC6 + CoO2 <===> C6 + LiCoO2

When fully charged the components on the left side are in the battery, when fully discharged the components on the right side.

ENERGY STORAGE

Energy Storage –Li-Batteries Current and Future Costs

Li-Battery cost have fallen enormously since 2010.

In 2010 the Lithium-Ion battery costs was $ 1000/kWh.

In 2019 the costs was reduced to $ 150/kWh.

It is expected that battery costs will continue to fall rapidly due to small improvements in technology and larger volume battery production. In fact, battery packs for buses in China in 2020 are already priced at $ 100/kWh.

BNEF estimates that average costs will be $ 96/kWh in 2025 and $ 70/kWh in 2030. However, CATL is already delivering batteries in 2024 at $ 58/kWh. These costs will make electric cars fully economic and will therefore have a large impact on possible oil demand.

ENERGY STORAGE

Energy Storage –Lithium-ion Batteries

Technical developments could also impact on the reduction of costs.

Scientists at the Lawrence Berkely National Laboratory have developed a polymer coating, called HOS-PVM coating, which ensures battery stability and higher charge and discharge rates.

The application of this coating permit the use of silicon in the electrodes which permits an increase of 30% in energy density.

It is anticipated that the coating could extend the life of the battery from 10 years to 15 years.

Sila Technologies is developing a nano-composite silicon (NCS) called "Titan Silicon" which could increase range with 20% and shorten charging times to 20 minutes.

ENERGY STORAGE

Energy Storage –Lithium-ion Batteries

A remarkable development may be that recently a joint team from POSTECH and Sogang University in Korea developed a functional polymer binder for stable high-capacity anode material that could extend the EV range 10-fold.

The breakthrough was achieved by replacing graphite with Si anode combined with layering-charged polymers.

The research has the capacity to significantly increase the energy-density of lithium-ion batteries.

ENERGY STORAGE

Tesla "Battery Day" (Sept 22, 2020) announcements

Tesla made a series of announcements related to many incremental improvements in battery capacity and lowering of its costs. Over the next three years Tesla expects the following:

-- reduction of battery costs per KWh by 56%,

-- improvement in driving range by 54%, and

-- lowering of capital costs per GWh of plants to produce batteries by 69%.

It is somewhat unclear as to against with baseline these percentages were determined and how they were calculated.

Much of the improvements center on a new tab-free Lithium-ion battery design, called 4680.

ENERGY STORAGE

Tesla "Battery Day" announcements

Apart from the 4680 design, the following improvements to lower overall EV costs and battery costs are also contemplated:

-- new stabilized silicon anodes,

-- new cobalt free cathodes, including very high capacity all nickel cathodes,

-- major improvements in cathode production costs,

-- make the structural rear of the car from a single casting, and

-- making the battery pack a structural element of the car, so it does not add to the weight of the car.

Tesla hopes to sell EV's costing $ 25,000 within the next three years (it should be noted that such a promise was not accomplished).

ENERGY STORAGE

Volumetric Energy Density

Ionblox a company specialized on delivery of high performances Li-batteries has develop a battery specifically aimed at electric vertical take of and landing vehicles (eVTOLs) with a volume energy density of 800 Wh/liter. In this case the anode is based on silicon-monoxide rather than graphite.

At the same time the capable power output is about 5 times higher than regular batteries.

This permits eVTOLs to have a larger range.

The batteries can be charged to 80% capacity in 10 minutes.

Ionblox is now targeting possibilities for road transportation.

ENERGY STORAGE

Volumetric Energy Density

One of the main drivers of the significant cost reduction of Li-batteries has been due to technologies able to increase the volumetric energy density of lithium-ion batteries very significantly.

In 2008 the density was 55Wh/liter.

CATL, the world's largest battery maker announced in 2022 that their cell-to-pack 3.0 battery systems will have a density of 290 Wh/liter for LFP (lithium-iron-phosphate) chemistry and 450 Wh/liter for NCM (lithium-nickel-manganese-cobalt-oxide) chemistry.

Since LFP batteries are cheaper, this means they are best used in utility type storage where volume is not a problem, while NCM batteries are generally better for cars.

ENERGY STORAGE

Other Lithium batteries - Volkswagen Solid State Battery

Volkswagen is backing QuantumScape Corporation in the development of a solid-state lithium-metal battery for the next generation of EVs.

This battery holds the promise of a step function increase over current battery technology with the following advantages:

-- an 80% longer range for vehicles,

-- a 15-minute charge to 80% capacity,

-- zero excess lithium and lower costs,

-- long life,

-- low temperature operation at – 30 degrees Celsius,

-- batteries are noncombustible and therefore safer.

ENERGY STORAGE

Other lithium batteries - Nissan Solid State Battery

Nissan is investing in a production facility for laminated all-solid-state battery cells, which it hopes to bring to market in 2028.

The Nissan cells would have:

-- an energy density of twice that of conventional lithium-ion batteries,

-- have much shorter charging times, and

-- be lower cost due to using lesser amounts of expensive materials.

Nissan believes they can achieve $ 75/kWh by 2028 and $ 65/kWh thereafter, making EVs fully competitive with gasoline-powered vehicles.

ENERGY STORAGE

Other lithium batteries - Theion Crystal Battery

A large number of car and other companies are working on dramatically improved battery designs.

An example is the Crystal Battery to be introduced by Theion, a German battery maker in Berlin.

This battery is based on a lithium-sulfur cathode technology, therefore not using cobalt or nickel. Instead, sulfur is used that is obtained as industrial waste product and does not require mining. It has no flammable components.

This battery is supposed to have triple the gravimetric and volumetric energy density, is fast to charge and has a long lifecycle.

ENERGY STORAGE

Lithium-Sulfur batteries - Stellantis

Stellantis invested in May 2023 in Lyten, an advanced matrial company specializing in lithium-sulfur EV batteries.

Lyten has achieved twice the energy density of typical Lithium-ion batteries, based on 3D graphene super material.

Stellantis aims at 100% electric vehicles in the European market and 50% in the US by 2030.

They have several brands including Jeep and Ram.

They hope to employ the Lyten batteries by about 2026.

Professor Qiao of the University of Adelaide, announced a carbon and cobalt-zinc catalyst that can charge Li-S batteries in 5 minutes.

ENERGY STORAGE

Lithium-Air Batteries

Researchers at the Illinois Institute of Technology and the US DOE Argonne National Laboratory have developed a new litium-air battery with a solid ceramic polymer-based electrolyte.

This has the potential to create <u>four times</u> the energy density of lithium-ion batteries.

With further research they hope to achieve a density of 1200 Wh/kg. The cell proved stable over 1000 charge and discharge cycles.

ENERGY STORAGE

Lithium Battery Storage Projects

The Huadian (Haixi) New Energy Company has successfully completed a 270M storage facility with a capacity of 1080 MWh in Haixi, Qinghai province, China.

It sits at an elevation of 3000 meters.

It is based on Lithium Iron Phosphate ($LiFePO_4$) battery storage systems provided by Sungrow.

ENERGY STORAGE

Metal availability for Li-Batteries

A major issue is the fact that most of the Li-batteries require costly metals that typically are only produced in a few countries. This may create upward pressure on costs and could result in supply problems.

For instance:

-- about 75% of the world cobalt production is in Congo,

-- about 80% of the world lithium production comes from Australia, Chile and China; Bolivia was reluctant to produce lithium from its giant salt flats, however, has now done a deal with Rosatom from Russia and Citic Guoan of China.

-- almost 50% of the world copper production comes from Chile, Peru and China, and

-- about 60% of the world nickel production comes from Indonesia, Philippines and Russia.

ENERGY STORAGE

Metal availability for Li-Batteries

In should be noted, however, that the shortage of these rare metals has created a strong incentive to increase supplies.

As a result, the cobalt production increased in Congo and significant new production has become available from Indonesia.

The cobalt price collapsed from $ 82,000 per ton in 2022 to $ 35,000 in 2023, near historical lows.

Also, entirely new methods to recover lithium may be developed. Geothermal brines that could produce geothermal energy often contain high lithium concentrations, up to 500 milligrams per liter. The Karlsruhe Institute of Technology has developed a sieve based on lithium-manganese with a special spinel-type crystal structure that can recover the lithium. So, in the future geothermal projects may be combined with lithium recovery.

ENERGY STORAGE

Metal availability for Batteries

A possible source of metals is the seafloor of the deep sea. The seabed is rich in nickel, cobalt and magnesium.

The deep sea outside the national territorial waters and continental shelves is subject to the 1982 UN Convention of the Law of the Sea.

The international seabed is governed by the International Seabed Authority (ISA).

The ISA has developed terms for exploration and granted exploration contracts to more than 30 contractors.

However, ISA has not yet developed the Mining Code. It is expected that this will happen in the next few years.

Japan offshore the island of Minami-Torishima has discovered in their EEZ offshore nodules with 230 million tons of manganese, also containing cobalt and nickel.

ENERGY STORAGE

Metal availability for Batteries

The "Global Critical Minerals Outlook, 2024" of the IEA reaches the following conclusions:

- **In 2023 prices for battery materials have declined significantly:**
  - **lithium – 75%,**
  - **Cobalt, nickel and graphite – 30% - 45%.**
- **However, 2023 demand remained robust with increases as follows:**
  - **Lithium – 30%**
  - **Nickel, cobalt, graphite and rare earths – 8% to 15%**
- **Nevertheless, today's oversupply is not a good guide for the future, because demand will continue to rise:**
  - **There is a significant gap between long term supply and demand of copper and lithium, while nickel and cobalt look tight.**
  - **The heavy concentration in Chinese production of graphite (90%) and rare earths (77%) could result in market disruptions.**

ENERGY STORAGE

Direct Lithium Extraction

ExxonMobil is in discussion with several car companies to supply lithium.

ExxonMobil has set a goal of extracting 100,000 tons per year of lithium is exploring and drilling a 10-acre site in Arkansas.

ExxonMobil believes there is a natural synergy between lithium and oil and gas production. The lithium would be recovered from underground salt water through wells.

This would be cheaper and more environmentally friendly than traditional mining.

ENERGY STORAGE

Direct Lithium Extraction

-- E3 Lithium is a company in Alberta with lithium leases which is in the process of preparing for production.

The lithium is extracted from a brine in a subsurface reservoir similar to petroleum production.

The direct lithium extraction process does not require evaporation. E3 Lithium is planning to produce battery-grade lithium hydroxide monohydrate ("LHM"). Its proven and probable reserves are over a million tons.

-- Cleantech Lithium operates similar projects in the Bolivia-Argentina-Chile triangle. Their main project is the Laguna Verde project with a reserve of 1.8 million tons at a concentration of 200 mg/liter lithium.

ENERGY STORAGE

Lithium for Li-Batteries

-- California has provided a tax credit of $ 30 million to Controlled Thermal Resources Holdings (CTR). CTR will invest $ 14.6 billion in the Salton Sea Geothermal Field to produce 50 MW of geothermal power and 25,000 tons per year of lithium hydroxide monohydrate.

-- The Pennsylvania Department of Environmental Protection suggest that the wastewater of the Marcellus shale gas wells would facilitate extraction of lithium of as much as 40% of the demand in the US.

-- EnBW of the Bruchsall geothermal power plant in Germany has produced high purity lithium carbonate from the lithium chloride in the geothermal waters.

ENERGY STORAGE
Recycling

-- An obvious solution to the possible mineral scarcity issues is recycling of battery materials.

In this respect BASF has started a prototype metal refinery for battery recycling in Schwarzheide, Germany.

The plant allows for the development of operating procedures and technologies to process end-of-life lithium-ion batteries.

BASF is a leading global supplier of advanced cathode active materials.

-- 9Tech in Venice, Italy, has a pilot plant in which under 400 degrees Celsius heat the polymers vaporize and with a mesh the plant is able to recover 90% of the silver, 95% of the silicon and 99% of the copper.

ENERGY STORAGE

Recycling

Princeton NuEnergy has developed a low temperature plasma-assisted process that creates battery-grade anode and cathode materials for direct use.

The process recovers 95% of the materials of a lithium-ion battery.

They are now planning to commercialize it.

ENERGY STORAGE

Other Classic Batteries

The possible lack of metal availability, is resulting in very intensive research and development to make batteries from other materials.

The most expensive part of the battery is the cathode, which uses the metals.

There are many possibilities, such as sodium-ion, sodium-sulfur, zinc-ion, calcium-metal, titanium-air, oxygen-ion, iron-chromium, nickel-zinc, sodium-aluminum, sodium-sulfur, ammonia-ion, iron-air, aluminum-ion, etc.

However, most of the alternatives still have problems to overcome.

ENERGY STORAGE

Other types of Classic Batteries

Researchers with Professor Donald Sadoway have developed an aluminium sulphur battery that may cost a sixth of the cost of a lithium-ion battery. Apparently, the battery can be charged quickly and lasts a considerable time.

The Rensselae Polytecnic Institute has developed an aqueous calcium-ion battery that is also potentially much cheaper than lithium ion.

Guosheng Li of PNNL has developed a sodium-aluminum battery molten salt battery, suitable for 12-24 hours storage for utility scale operations and eliminates the use of nickel. Although less efficient than lithium-ion batteries, it is anticipated to be considerably cheaper.

ENERGY STORAGE

Other Classic Batteries - Zinc Ion Battery

The Pohang University of Science and Technology, S. Korea, has developed a new zinc-ion battery with uses water as electrolyte. This promises greater stability and lower costs. Zinc-ion batteries have the potential to replace Lithium-ion batteries since the materials are low costs and there is no fire hazard.

The Oregon State University also invented a new electrolyte that can significantly improve the performance of zinc-ion batteries.

The Enerpoly Production Innovation Center will start a 100 MWh zinc-ion annual output plant in Rosenberg north of Stockholm.

ENERGY STORAGE

Other Classic Batteries - Zinc Iodine Battery

Researchers from the University of Queensland have developed a new solid state aqueous zinc-iodine battery with extended life span and high efficiency.

The batteries have received considerable attention because of natural abundance of zinc, low costs, safety and high theoretical capacity.

However limited life cycle was a problem.

Now the researchers have a solution with the development of fluorinated block copolymers which extend the lifespan.

ENERGY STORAGE

Other Classic Batteries - Zinc Oxide Battery

Fraunhofer IZM in Germany is developing a Zinc Hydrogen battery which is water based. When charging the Zinc Oxyde reduces to metallic Zinc and water oxidizes to Oxygen. When discharging the metallic zinc reverts to zinc oxide and the water releases hydrogen.

It is a unique combination of a battery that is also a source of hydrogen. The hydrogen can be used in a fuel cell of gas power plant to produce electricity.

The battery is ideal for long term storage and is made of cheap materials.

ENERGY STORAGE

Other Classic Batteries – Sodium-Ion Battery

The sodium-ion battery works in a similar way to lithium-ion batteries by shuttling sodium-ions between the positive electrode (cathode) and the negative electrode (anode) through an electrolyte, which is a sodium salt dissolved in a suitable solvent.

The cathode materials are typically sodium transition metal-oxides and the anode material is hard carbon.

During charging sodium-ions are released from the cathode and absorbed by the anode with the cell voltage gradually increasing.

During discharge the process is reversed.

Due to their low costs, sodium-ion batteries are ideal batteries for renewable energy storage. The market is expected to grow from 10 GWh in 2025 to 70 GWh by 2033.

ENERGY STORAGE

Other Classic Batteries – Sodium-Ion Battery

Due to the low energy density, it is anticipated that sodium-ion batteries will be mainly beneficial in the stationary market and mini-transport due to its low costs.

In this respect it is interesting to mention that China Southern Power Grid has deployed the first large scale sodium-ion battery at 10 MWh in the Guangxi Zhuang region, as a first phase of a 100 MWh project. The battery can be charged to 90% in 12 minutes.

With these batteries storage costs can be reduced with 20% or 30%. The cost per kWh maybe reduced to 2.76 cents.

A 100 MW/200MWh battery was developed in Qianjiang by the Dateng Group.

An interesting development is that POSTECH of Korea has developed a solid-state sodium-air battery.

ENERGY STORAGE

Other Classic Batteries – Natron Energy Sodium-Ion Battery

Natron Energy has started a sodium-ion battery plant in Holland, Michigan. The plant is aimed at a capacity of 600 MW per year.

Although sodium-ion batteries store less energy than lithium-ion, they are much cheaper.

The Natron batteries charge and discharge ten times faster than lithium-ion batteries with an estimated lifespan of 50,000 cycles.

The key technology is the Prussian blue structure, which consists of iron and manganese for the electrodes. They are non-flammable.

It is believed that the energy density of the batteries is 70 Wh/kg, which is relatively low compared to CATL. Nevertheless, they are believed to be economic for stationary storage.

ENERGY STORAGE

Other Classic Batteries - Iron-Air Batteries

Form Energy is developing iron-air batteries and is building a plant in West Virginia to produce them. The first commercial batteries are expected to be delivered in 2024.

The process is simple if electricity is applied to iron-rust it turns into metallic iron. Once oxygen is applied to the iron it creates electricity. It is a relatively slow process and therefore aimed at long duration storage of 100 hours or more. The California Energy Commission has approved a 5 MW/500 MWh to be constructed by Form Energy.

The huge advantage is that these batteries are very cheap and can store at 10% of the costs of typical lithium-ion batteries. The slow operation, however, indicates they are best used in combination with other battery types for longer duration grid fluctuations.

ENERGY STORAGE

Other Classic Batteries - Iron-Salt Batteries

Inlyte Energy is developing an iron-salt battery and received $ 8 million funding from At One Ventures.

This sodium metal halide battery is ready for commercial use and a pilot factory is being built.

The battery has a high efficiency, long lifetime, competitive energy density, excellent safety and is ultra-low costs.

The main market is thought to be the diurnal energy, four to 10 hour storage, for grid and industrial use.

ENERGY STORAGE

Other Classic Batteries – Potassium-ion Batteries

Group 1 in Texas has developed a Potassium-ion battery of an 18650 size.

It is based on Potassium Prussian White cathode material and paired with a commercial grade graphite anode along with readily available electrolytes and separators.

This battery is aimed at replacing lithium-ion batteries.

ENERGY STORAGE

Battery Electric Storage System ("BESS") Projects

Some large BESS projects are being creates, such as:

-- Libra Energy is planning a four-hour Bremer Battery Project of 850 MW/3400MWh in Queensland on a 16 hectare site.

ENERGY STORAGE

Weightless Carbon Fiber Batteries

Sinonus, a spin off of CTU (Gothenburg), has develop a carbon fiber batteries that can simply be integrated in the structural framework of any product.

The battery fulfills two functions: the structural component and a battery. This means a battery can be added to a car or airplane without creating additional weight of batteries, significantly reducing the total weight according to the creator Leif Asp.

The energy density is 24Wh/kg.

ENERGY STORAGE

Classic Batteries – Future costs and markets

The IEA predicts in its "Batteries and Secure Energy Transitions" report that batteries costs will drop in general about 40% by 2030.

For lithium-ion batteries for transport the focus will be on higher energy density and lower weight.

There is significant scope for cost cutting in energy storage batteries which can be larger and heavier. Sodium-ion will be a growing share in the market. Lithium-iron-phosphate batteries accounted for 80% of the storage in 2023.

The global market for storage in 2023 was 90 GWh. This is to grow six-fold by 2030. This will cut the electricity costs of mini-grids in half coupled with solar PV, helping millions of people to gain access to electricity.

ENERGY STORAGE

Flow Batteries - Zinc Flow Battery

Zinc-bromine flow batteries is long-lasting, non-flammable and fully recyclable. They are ideal for residential, commercial and micro-grid storage.

They release electricity back to the grid for hours or even days at a time.

Redflow has installed such batteries in already 200 projects world-wide. The largest installation is 2 MW in Rialto, California.

Various other companies are involved in zinc-bromide batteries.

Zinc8, a Canadian company, will invest in a zinc flow battery production plant in New York. The batteries are ideal for long duration applications, since all you need to do is to increase the tank of the zinc fuel.

ENERGY STORAGE

Large scale flow batteries

-- A large flow battery was commissioned in Dailan in China in 2022 and has a capacity of 100 MW/400 MWh at a cost of $ 298 million and is a Vanadium Redox Flow Battery (VRFB). This is the first phase. It is to be scaled up to 200 MW/800 MWh. Rongke Power supplied the battery technology.

-- In Sacramento, California, the plans are for 200 MW/2GW ten-hour iron flow batteries to be prepared by ESS Tech Inc.

ENERGY STORAGE

Flow Battery – Salt Water

The Norwegian company Statkraft and a Delft University based Dutch company Aquabattery are researching the possible use of salt water as a flow battery capable of providing electricity for any amount of time (depending on the scale of the tanks).

The system uses three tanks: fresh water, concentrated salt water and diluted salt water.

The system is charged by separating the diluted salt water in fresh water and concentrated salt water. Electricity is produced by recombining fresh water with the concentrated salt water to produce diluted salt water which results in electricity.

Since the system is using very cheap sources it has the potential to create long term cheap storage.

ENERGY STORAGE

Other Energy Storage – Mechanical

There is a wide variety of mechanical storage projects:

-- a mine near Adelaide, Australia, has a 5MW compressed air storage system, whereby compressed air replaces a water column and the water pressure produces electricity when needed.

-- Zhongchu Guoneng Technology has switched on the world largest compressed air project in a salt cave in China. It is a 300 MW/1800 MWh project in the Hubei province. The salt case is 1000 meter deep and has a capacity of over 500,000 m2.

-- Hydrostor is putting large bags on the floor of 55 meter deep Lake Ontario with compressed air. Water depth pressure releases the energy for electricity when needed. It is also working in California on a 500MW/5GWh massive compressed air project.

ENERGY STORAGE

Other Energy Storage – Mechanical

-- Max Boegl Wind AG plans to store water simply in the bottom of the towers of wind turbines, a project with a hydropower plant down hill of 16 MW capacity and with 13.6 MW wind.

-- China connected the largest 100 MW compressed air battery in Zhangjiakou in Hebei Province.

ENERGY STORAGE

Other Energy Storage – Mechanical - Pumped Hydro Storage

Pumped hydropower-based storage has been a traditional way of storing energy for any duration or volume.

Iberdrola opened recently the Tamega 1158 MW giga-battery in Portugal based on pumped storage, capable of storing 40 million kWh (40 GWh), sufficient to supply 11 million people for 24 hours.

Current (2019) world pumped storage capacity is 158 GW capable of delivering 9000 GWh of electricity. Capacity is expected to increase to 240 GW by 2030. The potential is huge; about 600,000 sites are available for pumped storage.

Currently about half the world pumped storage is installed in China, the USA and Japan, based on IHA data.

ENERGY STORAGE

Other Energy Storage – Mechanical - Pumped Hydro Storage

SE Asia is actively developing pumped storage.

In total the region will develop as much as 18 GW by 2033, with new projects in Vietnam, Thailand, Indonesia and the Philippines.

ENERGY STORAGE

Other Energy Storage – Mechanical - Pumped Hydro in a Mine

-- A Finnish abandoned mine is to host a 75 MW/530MWh pumped hydro storage and will generate between 60 and 160 GWh per year. The mine is 1444 meters deep.

The company EPV Energy will own the project.

It is anticipated to be constructed in three years and will be operational by 2026.

-- Evolution Mining is developing a 2GW/20GWh pumped hydro facility in an old gold mine in Australia, called Mount Rawdon in Queensland. The mine is supposed to be closed in 2027 and will be subsequently converted.

ENERGY STORAGE

Other Energy Storage – Mechanical – Well based pumped storage

Quidnet Energy has teamed up with Hunt Energy Network to delivery 300 MW of well based pumped storage to ERCOT in Texas.

The technology is low costs.

It consists of a water well connected to a sealing underground reservoir as well as a pond.

Excess electricity is used to pump water from the pond down in the reservoir under high pressure. When energy is needed the well is opened and water is released creating electricity.

It should be noted that such a system could be used in many areas in the world.

ENERGY STORAGE

Other Energy Storage – Gravity

-- An American-Swiss startup Energy Vault plans to use simple gravity by lowering multiple ton weights to generate electricity in a large building of 100 meters high (“Energy Vault Resilience Centres”) that could cover between 1.5 and 20 acres. Electricity can be stored for long or short term and used whenever needed. Their first 25MW/100MWh system is operational in China and is currently planning together with ENEL a facility in Texas.

-- the International Institute for Applied Systems Analysis (IIASA) (Laxenburg, Austria) has developed a new idea to use tall buildings as energy storage. This can be done through Lift Energy Storage Technology (LEST).The lifts of buildings are simply used to store energy through gravity.

ENERGY STORAGE

Other Energy Storage – Electrical

Important developments are taking place in the creation of more efficient or cheaper super-capacitors. These are used to deliver short burst of energy or absorb quickly large amounts of energy:

-- Indian scientist at the International Advanced Research Center for Powder Metallurgy and New Materials have developed a very low-cost super-capacitator based on nanostructured nickel-cobaltite.

-- Researchers at MIT have made the remarkable discovery that the mixture of cement, water and up to 10% carbon black makes a very powerful low-cost capacitator.

ENERGY STORAGE

Other Energy Storage – Thermal

There is a wide variety of thermal storage projects:

-- a 50 MW-400 MWh liquid air storage project is being installed in Vermont, with air being cooled to minus 196 degrees Celsius which is allowed to warm and produce power when needed.

-- Siemens in Hamburg, Germany has a thermal storage project of 1.2MW/130MWh capacity, with heated air that produces steam when electricity is needed.

-- RayGen in Australia is pursuing a Solar-Hydro storage system, whereby 4MW Solar CSP is stored in a thermal storage system of 3MW-50MWh (17 hours) of storage. It is based on an Organic Rankine Cycle turbine operating between two water reservoirs at 90 and near zero temperatures, heated with waste from the solar PV system.

ENERGY STORAGE

Other Energy Storage – Thermal – CO_2 storage

Energy Dome, and Italian startup, will install the first CO_2 battery in the US for utility purposes, storing energy from solar and wind.

CO_2 can be easily liquified. Therefore, with excess energy large volumes of CO_2 can be stored. When electricity is needed all that is required is to heat up the CO_2 and the expansion of the gas creates the production of electricity.

This was incentivized by the recent Inflation Reduction Act.

First production is expected in 2024.

The company has already fully tested a 4MWh battery in Sardinia for the Italian utility A2A.

The US entry is supported by the investment portfolio of Elemental Excelerator

ENERGY STORAGE

Other Energy Storage – Thermal – Liquid Air Storage

Highview Power is constructing the first long duration liquid air storage plant in the UK, located in Carrington, Manchester.

The storage capacity will be 50 MW/300MWh.

Energy storage could be for several weeks.

ENERGY STORAGE

Other Energy Storage – Thermal – "Sun in a Box"

Boston based Fourth Power has created a thermal battery that can deliver energy to thermophotovoltaic (TPV) cells at any time electricity is required. They claim it is ten times cheaper than lithium-ion batteries.

The thermal battery works by heating liquid tin on a closed loop basis to heat stacks of carbon blocks until the glow white hot with temperatures of 2400 degrees Celsius.

When power is needed the system exposes TPV cells to the light emitted and converts it into electricity.

They can meet short duration and long duration power needs.

They expect to have a 1 MWh-e prototype ready by 2026.

ENERGY STORAGE

Other Energy Storage – Thermal – Rondo Energy

Rondo Energy, a California start-up, produces super hot bricks that can contain heat at 1500 degrees Celsius.

Renewable energy can generate the heat.

Subsequently the heat can be sold as heat or steam for industrial processes.

Together with Portugal-based EDP in total 2 GW will be installed in Europe starting 2025.

ENERGY STORAGE

Other Energy Storage – Thermal - Heat Storage

A way to store energy is to store it directly as heat.

Vattenfall has a giant hot water storage facility in Berlin, 45 meters high, holding 56 million liters of water for a district heating system. The water is heated using excess wind and solar energy when not needed for other purposes.

Polar Night Energy installed in Finland a steel container heating sand to 500 – 600 degrees Celsius. The capacity is 100 kW for 8 MHh storage, which means 80 hours of storage. However, the plan is to scale up to 8 GWh for a project in the UK.

Sandia National Laboratories has built a simple heat storage based on rocks. The system was charged to 500 degrees Celsius and retained the heat for 20 hours.

ENERGY STORAGE

Other Energy Storage – Thermal – "Smart" Water Heaters

The UTS Institute for Sustainable Futures in Australia, studied the possible effect of "smart" electric water heaters.

A 300-liter hot water tank can store as much energy as a Tesla Powerwall – at a fraction of the costs.

High energy efficiency can be obtained using electric heat pumps to heat the water.

As Australia achieves a high level of electricity generation based on renewables, the savings relative to continuing with gas-fueled water heaters will be about US $ 4 billion per year. It would create 30 GWh of flexible demand capacity, savings 2 million home batteries.

ENERGY STORAGE

Other Energy Storage – Thermal - Heat Storage

A different way is to store heat is to use molten salts.

A possible interesting new different process is the water and salt heat battery developed by the University of Technology of Eindhoven and partners in the Netherlands. The process is cheap, compact and completely loss free. The concept is very simple: if you add water to salt, significant heat is produced. If you want to store the heat just evaporate the water and the dry salt can be stored indefinitely. A device is produced that is suitable for home heating of 70 kWh and is currently being pilot tested. The advantage of the system is that it can use industrial waste heat. It could take 3.5 million Dutch homes off natural gas.

ENERGY STORAGE

Other Energy Storage – Thermal - Thermal Battery

Engineers at the Lehigh University of Pennsylvania, with support from DOE, have developed a low cost and highly efficient thermal battery, called the Lehigh thermal battery.

The are ready to market a 150 kWh (thermal) battery.

Heat inputs are from concentrated solar power, nuclear energy plants, natural gas plants, etc. as well as renewable electricity.

Outputs are process heat or steam that in turn can be used to produce electricity.

ENERGY STORAGE

Heat Storage to Electricity

MIT and NREL are working on thermophotovoltaic (TVP) cells that can convert heat directly in electricity with an efficiency of 40%.

The University of Michigan has created TVP cells with 44% efficiency.

This is more efficient that a regular steam engine of 35%.

This is based on high temperature heat of 1900 to 2400 degrees Celsius.

Excess renewable energy can be converted in heat and stored in heavily insulated banks of hot graphite. TVP cells would convert the heat to electricity whenever needed.

ENERGY STORAGE

Other Energy Storage – Geothermal

The Houston based Fervo Energy has done the reservoir simulations to prove that using wind and solar energy to create heat in geothermal reservoirs is an economic way to store energy compared to Li-batteries.

The raised $ 138 million for a venture to create an Enhanced Geothermal System (EGS) which is really drilling horizontal wells and creating artificial reservoirs of fissures in hot dry rock which is sealed off, which can be filled with hot water which can be produced subsequently. They claim the system will be 90% efficient in terms of supplying and producing heat.

ENERGY STORAGE

Energy Storage – Competitiveness

BloombergNEF completed its first "Long-Duration Energy Storage Cost Survey". It is a study of 7 technology groups and 20 different types.

The conclusion is that for 4-hour storage thermal and compressed air storage is cheaper than lithium-ion. Capex requirement are $ 232 per kWh for thermal and $ 293 for compressed air. This compares with $ 304 for lithium-ion.

Also, some flow batteries are commercially successful.

Gravity storage is more expensive.

ENERGY STORAGE

Combinations: Batteries & Pumped Hydro

In Poland the PGE Group is constructing a 205 MW/820 MWh project based on Lithium-ion near Zarnowiec. This project will be integrated with an existing 716MW/3600MWh pumped hydro project as well as 3.5 GW of possible future wind generation. The project will have a cable link to Lithuania.

ENERGY STORAGE

Combinations: Flow Batteries & Ultra-Capacitators- Salgenx

A US based startup has integrated ultracapacitators with a saltwater redox flow battery (SRFB).

The system uses salt water and a proprietary electrolyte. It does not use lithium or vanadium and is membrane free. This could lower the LCOS. It has a high energy density.

The combination with ultra-capacitators will permit high level performance under rapidly changing loads, creating rapid power output in milliseconds.

The system performs well under long duration energy storage with irregular power bursts.

ENERGY STORAGE

Energy Storage – Utility Scale Storage - Costs

The Lazard 2023 estimate of current utility scale storage including solar PV is between LCOS is between 11.0 and 13.1 cents/kWh and for onshore wind between 6.9 and 7.9 cents/kWh (Lazard assumes a different financing structure compared to the earlier table on energy costs).

ENERGY STORAGE

Energy Storage – Utility Scale Storage – 2030 Costs

For the year 2030 the Lazard LCOS can be adjusted by taking into consideration our estimate of the costs of solar of 3 cents/kWh kWh and battery costs of $ 70/kWh.

This will result in a LCOS of between 11 and 22 cents/kWh (2020$), in other words competitive in a significant part of the world with gas peaking after sunset. However, this is based on Lithium-Ion batteries.

It is believed by some experts that flow batteries by that time may actually be cheaper and will be longer lasting, due to anticipated further technical developments of these batteries.

ENERGY STORAGE

Energy Storage – DoE Roadmap for 2030

Against the above cost projections, the US Department of Energy has published a roadmap to achieve low-cost storage by 2030, called "Energy Storage Grand Challenge". It is an integrated approach to support the R&D, development and installation of energy storage.

With respect to utility scale long term storage the goal is to achieve a LCOS by 2030 of 5 cents kWh. This is for a 100MW- 10 hour storage system. A wide variety of storage systems is supported by the program.

Apart from pumped storage hydropower, it seems that redox flow batteries, compressed-air energy storage, "sun-in-the-box, iron-air batteries are the best candidates to achieve this goal.

ENERGY STORAGE

Energy Storage – Utility Scale Storage – 2050 costs

A huge amount of research and development is currently being done to develop even cheaper storage systems of every possible type. Seven countries of the EU have approved a 3.2 billion Euro research project to make Lithium-ion batteries last longer and faster charging.

It is the Van Meurs estimate that the DOE objective of achieving long term utility scale storage for less than 5 cents per KWh will be achieved by 2030. Intensive further research may lower these costs to 4 or even 3 cents per KWh by 2050.

ENERGY STORAGE

Energy Storage – Utility Scale Storage – Research

A huge amount of research is being done with respect to energy storage. Following is a sample:

Elestor, a company in the Netherlands, is working on a hydrogen-bromide flow battery aimed at relatively small scale storage. A 50 kW demonstration project is underway. Larger size storage can be created by simply more 50kW units. The battery is therefore made of light and cheap materials. A battery with any combination of power (kW) and capacity (kWh) can be designed. The battery has a very long life time (more than 10,000 cycles) without affecting the quality of the battery. Charge to discharge is in the 100 microsecond range. Research (supported by Shell) is being done to even have a membrane-less flow battery, thereby significantly reducing further potential costs.

ENERGY STORAGE

Energy Storage – Utility Scale Storage – Research

Apart from the Dutch example, following are some other examples of possible new battery technologies under research or development:

-- The University of Freiburg is working on a non-aqueous all-manganese flow battery,

-- ESS Inc. (USA) works on all-iron flow batteries.

-- Volkswagen supports Northvolt partnering with Stora Enso to develop hard carbon anodes made of lignin from wood.

ENERGY STORAGE

Energy Storage – Conversion of Coal Power Plants

Researchers in the Technical University of Denmark have come up with an idea to convert coal power plants using Carnot batteries.

Carnot batteries can store and release electricity as heat using different materials such as water, molten salt or rock. They can also use different techniques such as liquid air, thermal cycles or sorbtion techniques.

Coal plants are the ideal location since the infrastructure is already there for grid connection and can operate on a large scale.

The batteries can store excess solar and wind energy as heat and deliver electricity when needed.

ENERGY STORAGE

Energy Storage – Highly Variable Load

Lithium-ion batteries could also be a valuable method of energy storage to lower emissions from equipment with a highly variable load.

An interesting example is the West Mira ultra deep-water drilling rig in the North Sea, which is the first hybrid rig developed by Siemens, Seadrill and Northern Oceans. The rig has a 6 MW-166MWh ultra-safe battery system which operates at peak energy use, thereby significantly reducing the diesel consumption of the rig and the required capacity of the diesel generators.

Similar applications are possible for a wide range of other types of equipment with highly variable loads.

RENEWABLES PLUS STORAGE

Solar plus Storage Projects

-- The Spanish PV group Sivortex is planning 100 MW of solar with 200 MWh of liquid CO2 storage.

-- The Tashkent Riverside project in Uzbekistan will have 200 MW solar and 500 MWh battery energy storage.

-- Solar Energy Corp of India (SECI) has concluded a solar plus storage tender with an average price of 4.1 cents/kWh. The tender was for 1.2 GW with 600 MW/1.2 GWh of storage. The PPA is for 25 years. The winners were Acme Solar Holdings, Hero Solar Energy, JSW Neo Energy and Pace Digitec Infra.

-- The Edwards&Sanburn solar plus storage project is largest in the USA with 864 MW of solar and 3287 MWh of storage involving 1.9 million solar panels on 4660 acres, with a storage costs of 2 to 3 cents/kWh.

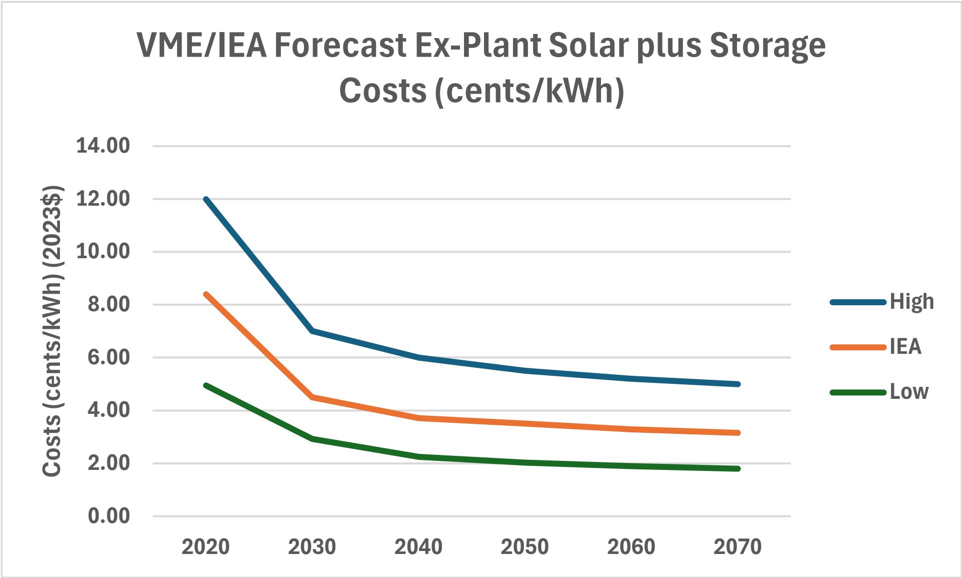
RENEWABLES PLUS STORAGE

Solar plus Storage Projects

-- The 8minute solar plus storage project in Eland had a PPA price of US $ 39.62/MWh. It has 400 MW of power and 300 MW/1200MWH of storage. This was still subject to the US tax credit.

RENEWABLES PLUS STORAGE

Solar plus Storage



The IEA forecast is based on 100 MW of solar plus 20MW/80MWh of storage. Obviously, there is a wide range of costs that can be estimated due to geographical differences and the amount of storage connected to the solar. This VME range is reflected in the forecast.

RENEWABLES PLUS STORAGE

Renewable plus Storage Projects

-- Solar Energy Corp of India has allocated 480 MW of renewables plus storage at 6.8 cents/kWh. The project is developed on a build-own-operate basis.

-- Bulgaria is planning the Tenovo Solar plant with 238 MW solar, 237 MW wind and 250 MW-500 MWh storage.

-- Vattenfall opened the Energy Park Haringvliet in the Netherlands with 38 MW of solar, 22 MW of wind and 12 MWh of storage.

-- The Forest's Clark Creek project in South Australia will have 1200 MW of wind, 600 MW of solar and 900 MW of storage.

-- In Chile, Engie won a contract to build two hybrid wind-solar-storage projects of 1,500 MW in total.

RENEWABLES PLUS STORAGE

Renewable plus Storage Projects

- Squadron Energy intends to construct a large hybrid project in New South Wales, called the Koorakee Energy Park, consisting of 1 GW of solar, 1 GW of wind backed up by 1GW/12 GWh of storage.
- The German Federal government concluded a renewables tender combined with storage. The average price was 8.9 cents per kWh.

RENEWABLES PLUS STORAGE

Microgrids

An important development in Hybrid Projects are integrated microgrid systems where solar, wind, storage and an “intelligent” Integrated Energy Management System are combined to deliver 100% renewable energy.

Many new startups are entering this field. An example is Hover Energy, Dallas, which will start delivering integrated systems from 2023.

Integrated microgrids offer security in case of power outages.

The 36-kW test microgrid of Hover Energy survived hurricane Ian in Florida.

HYDROGEN

Hydrogen

Hydrogen has the potential to become enormously useful in the climate change strategies.

This is because hydrogen can produce electricity and can be used for combustion. Upon producing electricity or combustion it produces only water.

Therefore, this is a very clean fuel.

HYDROGEN

Hydrogen

Cost and production of hydrogen is often expressed in kilogram (kg) of hydrogen.

The energy content of 1 kg of hydrogen is 115,240 Btu.

One MMBtu requires 8.68 kg of hydrogen.

One barrel of oil equivalent is about 50 kg of hydrogen.

One kg H2 has the same energy content as 11.2 cubic meter of H2

HYDROGEN

Hydrogen – Current production methods

Currently about 70 million tons of (pure) hydrogen is produced in the world as feedstock for a wide variety of purposes, such as for refining of crude oil, producing ammonia and methanol and as fuel for cars.

Almost all hydrogen is currently produced through a variety of industrial processes from fossil fuels, such as:

- **steam reforming of methane,**
- **partial oxidation of methane, and**
- **gasification of coal or biomass.**

A negative aspect of these production methods is that they produce huge volumes of CO_2 as by product.

Therefore, other methods of production are actively being pursued.

HYDROGEN

Hydrogen Production – Color codes

There are many ways of producing hydrogen. They are often expressed in color codes. The traditional codes are as follows:

-- Grey – produced from methane as indicated above

-- Blue - Grey hydrogen with carbon capture of CO2

-- Green – produced based on electrolysis with electricity from renewable energy sources

-- Brown – based on gasification of lignite

-- Black – based on gasification of bituminous coal

-- Turquoise – based on pyrolysis of methane producing carbon black and hydrogen

-- Purple – using nuclear power and heat through combined chemothermal electrolysis of water

HYDROGEN

Hydrogen Production – Color codes

(continued):

-- Pink – using nuclear electricity for electrolysis of water

-- Red – using very high temperature catalytic splitting of water

-- White – naturally occurring hydrogen or produced through processes from geological formations

However, further methods are also under R&D or under development, so in this presentation more colors are used:

-- Yellow – direct conversion of solar energy to hydrogen using special solar cells

-- Beige – biomass or municipal waste gasification with industrial use or emission of CO_2 or low biogenetic CO_2 emissions

-- Orange – any other method not emitting green house gases

HYDROGEN

Green Hydrogen – Electrolysis

Green hydrogen is based on electrolysis, which is a process that uses an electrolyzer. This is a system that uses electricity to break water into hydrogen and oxygen.

In its most basic form, an electrolyzer contains a cathode (negative charge) and an anode (positive charge) separated by a membrane (called electrolyte) and surrounded by water. Electrolysis transforms electrical energy into chemical energy by storing electrons in stable chemical bonds. This chemical energy can be used as fuel or converted back to electricity as required.

At the anode the water is oxidized to oxygen. At the cathode the water is reduced to hydrogen gas.

HYDROGEN

Green Hydrogen –- Electrolysis

Hydrogen is called "green" when the electrolysis is based on electricity generated from solar, wind, hydropower or geothermal energy. There are in turn four main methods of electrolysis:

.. Alkaline electrolyzers (ALK)

.. Proton exchange membrane electrolyzers (PEM)

.. Solid Oxide Electrolyzer (SOE)

.. Anion Exchange Membrane Electrolyzers (AEM)

An electrolyzer requires 50 – 55 kWh of electricity to produce a kg of hydrogen. The hydrogen can be converted back to electricity with a fuel cell, which can produce 33 kWh of electricity from a kg of hydrogen.

HYDROGEN

Green Hydrogen – Electrolysis - AEL

Alkaline electrolysis (AEL) has been used for 100 years. Often potassium hydroxide is the electrolyte. The following formulas illustrate the chemical process:

Cathode: 2H2O + 2e > H2 + 2OH

Anode: 2 OH > (1/2)O2 + H20 + 2e

When current is applied to the cell stack, at the cathode water is split into hydrogen and hydroxide anions which move through the diaphragm to recombine at the anode to O2.

Commercial AELs operate at a temperature of 100 – 150 degrees Celsius. They do not need rare metals but are somewhat bulky equipment. AEL has the lowest installed costs. Large systems sizes are possible.

HYDROGEN

Green Hydrogen – Electrolysis - PEM

Proton Exchange Membrane Electrolysis (PEM) is relatively new. The following formulas illustrate the chemical process:

Cathode: 4H + 4e > 2H2

Anode: 2H20 > 4H +O2+ 4e

At the anode water is split into hydrogen ions and oxygen. From the anode electrons move through an external circuit to the cathode where they combine with the hydrogen ions that pass through the membrane to the cathode to form hydrogen.

Commercial PEMs operate at a temperature of 70- 90 degrees Celsius. When they are fed with pure water, they produce very pure (99.999%) hydrogen. The disadvantage is that PEMs use a considerable amounts of rare metals. They can be made in small units.

HYDROGEN

Green Hydrogen – Electrolysis - SOE

Solid Oxide Electrolysis (SOE) is a high temperature process and uses a solid ceramic material as electrolyte. The following formulas illustrate the chemical process:

Cathode: $H2O + 2e > H2 + O$

Anode: $O > (1/2)O2 + 2e$

At the cathode water and electrons from an external circuit are combined into hydrogen and negatively charged oxygen ions. The oxygen ions are transported through the membrane to produce oxygen gas and electrons for the circuit.

Commercial SOEs operate at a temperature of 700 – 800 degrees Celsius. There are significant possibilities for future development.

HYDROGEN

Green Hydrogen – Electrolysis – SOE- Low Cost

Hadean Energy, a company created by the Australian research organization CSIRO and RFC Ambrian, have developed a new type of low-cost Tubular SOE.

They are constructing a pilot project.

It is believed that this technology could be most efficiently combined with industrial waste hear, since SOE works under high temperatures.

Costs can be reduced by 30% compared to PEM or Alkaline electrolysers.

The Korea Institute of Science and Technology reported a new perovskite based nanocatalyst that may reduce costs of producing hydrogen significantly.

HYDROGEN

Green Hydrogen – Electrolysis - AEM

Anion Exchange Membrane Electrolysis (AEM) is similar to PEM with the difference that the membrane transports OH anions instead of hydrogen protons. It uses the same process in the electrodes as alkaline electrolysis. The following formulas illustrate the chemical process:

Cathode: $4H_2O + 4e > 2H_2 + 4OH$

Anode: $4OH > 2H_2O + O_2 + 4e$

One of the key advantages is that the membrane is less expensive than PEM, while it also produces high purity hydrogen at high pressure. It is a low temperature electrolysis. Small systems possible. However, the technology is not yet fully mature.

HYDROGEN

Green Hydrogen – Electrolysis – from Hydro

The key to low-cost electrolysis is low-cost electricity.

Therefore, countries with low-cost hydro are in a good position to become hydrogen producers.

For instance, Tajikistan is planning to become an important hydrogen producer.

Switzerland is producing hydrogen at the Shiffenen dam.

Iceland may export hydrogen to Rotterdam.

HYDROGEN

Green Hydrogen – Electrolysis – from Solar

Montana Technologies and Climate Impact Corporation are cooperating to try to produce hydrogen at less than $ 2 per kg in desert environments.

The technology is based on the AirJoule water generator that can extract water from even desert air.

This permits the combination of solar, AirJoule water and electrolysers to produce hydrogen in desert environments with ample sunshine low costs.

HYDROGEN

Green Hydrogen – Electrolysis – from Solar or Wind

Griffith University in Australia has improved the LCOH model for estimating hydrogen costs by taking the variability of electrolysers into account.

They evaluated several areas in Australia and came to the conclusion that based on a WACC of 6% hydrogen can be produced at less than $ 2 per kg in the Gladstone area.

HYDROGEN

Beige Hydrogen – Production methods

A beige production method is biomass gasification:

-- Currently a large project is the $ 1.4 billion plant to be constructed in Oman by an American company called H2 Industries. The plant will use municipal waste to produce 67,000 tons of hydrogen per year and 1 million tons of industrial CO2 for exports.

The plant will initially use 1 million tons per year of municipal waste and can be expanded to 4 million tons. The project involves 300 MW of solar energy and 70 MW or storage.

HYDROGEN

Beige Hydrogen – Production methods

A Louisiana biomass-fueled plant will produce hydrogen and CO2 using a process developed by Babcock & Wilcox, starting mid-2026.

B&W said its BrightLoop technology is a chemical looping technology that can produce hydrogen from nearly any feedstock, including solid fuels, such as waste wood.

The process produces an isolated stream of CO2 for use, capture or sequestration, as well as nitrogen that can be used to produce ammonia.

HYDROGEN

Beige Hydrogen – Production methods

SGH2 in planning to construct a plant in Lancaster, California, that will use a high temperature plasma arc technology.

Waste material is turned in a plasma at temperatures of 3000 to 4000 degrees Celsius, which completely ionizes the gas.

From this gas pure hydrogen is being produced. Small amounts of biogenetic CO_2 are off-gassed.

In total the process is carbon negative. SGH2 calls it therefore a “greener than green” plant or “dark green”.

The Lancaster plant will produce 12 tons of hydrogen per day. It is estimated that the costs are $ 2 - $ 3/kg.

HYDROGEN

Yellow Hydrogen – Production methods

Yellow hydrogen is a direct solar to hydrogen process. This is a process whereby solar energy is directly converted in hydrogen without electrolysis based on specially designed solar cells. Various universities are working on this.

-- Progress has been made by the Australian National University (ANU), which claims having achieved a 17.6% efficiency by using a silicon/titanium/platinum photoelectrode which splits water directly in hydrogen and oxygen. Repsol is also evaluating this technology for possible hydrogen production.

-- University of Tokyo and ARPChem claim to have achieved 12% efficiency.

HYDROGEN

Yellow Hydrogen – Production methods

(continued:)

The University of Leuven, Belgium, has developed another direct solar to hydrogen process for rooftop panels. They have developed a commercial type panel, called Solhyd panel, which generates 250 liters (0.022 kg) of hydrogen per day with 15% efficiency. The panels split water (taken from the atmosphere) and produce hydrogen. The panels are compatible with typical PV mounting structures. However, instead of being connected to electricity, they are connected with low pressure gas tubes. The hydrogen can be burned directly or stored in compressed form or could be liquified for commercial purposes.

The University has gradually improved the panels and claims it is now ready for MW applications.

HYDROGEN

Turquoise Hydrogen – Production methods

Direct clean energy conversion of methane through pyrolysis produces hydrogen and carbon black. In this case methane is only used as feedstock. With electricity from renewable resources, the hydrogen is carbon-free.

This process is sometimes called "turquoise hydrogen"

A company in Nebraska, US, Monolith Materials is already having a commercial scale emission free facility producing 14,000 metric tons of carbon black per year and hydrogen.

HYDROGEN

Turquoise Hydrogen – Production Methods

(continued:)

Aarhus University (Denmark) is working on adopting the "turquoise hydrogen" to biogas.

If biogas is being used the production of hydrogen, it results at the same time in permanent removal of CO2 from the atmosphere (negative carbon).

They are trying to find metal catalysts that significantly reduce the temperatures for pyrolysis and therefore saving the renewable energy used for the process. They believe they can produce hydrogen with one fifth of the energy used typically in electrolyzers.

HYDROGEN

Red Hydrogen –Production methods

- **Potentially, the Heliogen process (as previously mentioned under "Solar Heat") producing HelioFuel or any other thermochemical process. There are about 300 different thermochemical processes under which hydrogen can be produced directly from solar energy in temperature ranges of 850 to over 1400 degrees Celsius.**
- **MIT has developed a thermochemical process to use 40% of the solar heat to produce clean hydrogen fuel. It uses a train-like system of reactors with a hot station (at 1500 degrees Celsius) to a cold station (at 1000 degrees Celsius) to produce STCH (solar thermochemical hydrogen). They aim to reach the goal of $ 1/kg by 2030.**

HYDROGEN

White Hydrogen – Production methods

-- Interestingly, in Mali a company called Hydroma Inc. is producing natural hydrogen from drilled gas wells, 60 km northwest of Bamako. The company has launched exploration in Canada and Australia. In this case, it is considered that hydrogen is present and produced inorganically deep in the earth crust and moves upward through the crust.

-- France, accidentally discovered a large hydrogen deposit of 46 million tons in Lorraine.

-- Gold Hydrogen may produce hydrogen from the Ramsey deposit in South Australia.

-- The Rider Natural Hydrogen Project by Max Power Mining in Saskatchewan covers over 3000 sq km.

HYDROGEN

Hydrogen – from gas wells

- Proton Technologies indicates that they can produce hydrogen through underground oil sand oxidation at about $ 0.50/kg
- Researchers from the Skolkovo Institute and Science and Technology also claim that hydrogen can be produced from gas wells by injecting water and a catalyst in an injection well, causing thermocatalytic conversion of methane gas through a combustion front causing syngas and selectively through a membrane producing pure hydrogen from a production well.

HYDROGEN

White Hydrogen – Hydrogen from iron-rich rocks

Hydrogen from iron-rich rocks. Toti Larson at the University of Texas is working on producing hydrogen from iron-rich rocks through serpentinization.

During this process hydrogen is released as a by product.

Serpentinization is usually taking place at high temperatures.

The team is working on catalysts to produce hydrogen at lower temperatures and therefore lower depth.

HYDROGEN

Orange Hydrogen – Production Methods R&D

There is a massive amount of R&D under way that may change the future of hydrogen production based on entirely different processes. For instance:

-- Researchers at the University of Southampton have indicated that they can produce hydrogen with solar energy by transforming optical fibers into photocatalytic micro-reactors.

-- the University of Ontario Institute of Technology is producing hydrogen through dissociation of water vapor into hydrogen gas by microwave generated plasmolysis.

-- production of biohydrogen based on a photobioreactor using algae, which switch from producing oxygen to hydrogen when deprived of sulfur.

HYDROGEN

Orange Hydrogen – Production Methods R&D

(continued:)

-- Two processes are based on aluminum without using electricity:

…. Laureen Meroueh PhD of MIT is developing methodologies to produce hydrogen by simply allowing aluminum to react with water, creating aluminum hydroxide and hydrogen. Aluminum from scrap yards can be used. GH Power, a Canadian firm, is planning to use this process.

…. The UC Santa Cruz showed that an easy composite of gallium and aluminum creates aluminum nanoparticles that react with water to create large amounts of pure hydrogen. The gallium is easily recoverable.

HYDROGEN

Orange Hydrogen – Production methods R&D

(continued):

-- Peter Edwards of Oxford University is microwaving plastic, which strips the hydrogen from the plastic and leaves carbon nanotubes. Plastic contains about 14% hydrogen by weight. It can also be extracted through polymer photo-reforming.

-- Sophia Haussener of the Laboratory of Renewable Energy Science and Engineering (Lausanne) is using a parabolic mirror using solar energy to create high temperatures which with a photoelectrochemical reactor produces hydrogen, oxygen and excess heat.

-- Researchers from Tel Aviv University have produced hydrogen using a biocatalyst. The method is based on electricity, using a hydrogel to attach the enzyme to the electrode.

HYDROGEN

Other production methods - Batteries

-- Battolyser systems is a Dutch startup that uses the Edison battery to produce more efficiently hydrogen. The claim that costs could be as low as $ 1.50 per KG by 2025.

-- They hope to his 1 GW of production capacity by 2026. The hydrogen is produced through electrolysis. The technology is based on nickel-iron electrodes.

HYDROGEN

Oxyhydrogen

An entirely different approach is to produce oxyhydrogen (HHO) gas as a fuel.

-- ENECO Holdings in Japan announced a new catalytic process that reduces the cost of HHO fuel from $0.93 to $ 0.28/m3.

HYDROGEN

Hydrogen – Production Costs based on fossil fuels

Currently costs are still high. IRENA is of the view that current green hydrogen costs based on cheap solar, or wind is about $ 3/kg.

In 2023 the European Union launched its first green hydrogen auction with a ceiling price of 4.50 Euro/kg. The winners will receive subsidies to close the gap with hydrogen from fossil fuels. The purpose is to create a European Hydrogen Bank. The goal is to produce 10 million tons by 2030.

In order to benefit from green hydrogen, it is crucial that the costs of producing green hydrogen become less than grey hydrogen.

Therefore, we will first analysis costs based on hydrogen from fossil fuels

HYDROGEN

Hydrogen – Production Costs based on fossil fuels

The US National Energy Technology Laboratory (NETL) did in 2022 a detailed study of costs of hydrogen from fossil fuels.

This study is an important benchmark for guidance as to whether green hydrogen is economic compared to grey or blue hydrogen.

The analysis determined the levelized costs of hydrogen (LCOH) in 2018 dollars. Based on a natural gas price of $ 4.42 per MMBtu, the study resulted in the following costs per kilogram:

- steam reforming of natural gas, no CCS - $ 1.06, with $ 0.77 representing natural gas costs,
- steam reforming of natural gas, with CCS - $ 1.64, with $ 0.82 representing the natural gas costs.

Processes based on coal gasification ranged from $ 2.58, no CCS to $ 3.09 with CCS.

HYDROGEN

Hydrogen – Costs based on Fossil Fuels – Impact of gas prices

The logical conclusion of the NETL study is that fossil fuel-based hydrogen costs based on natural gas are extremely sensitive to the price of gas.

During April 2022, the LNG Asian spot market (Platts JKM) jumped to $ 84.76 per MMBtu, while the European LNG spot market reached $ 51 per MMBtu, largely as a result of the Russia-Ukraine conflict. The European price imported in the NETL calculation of the previous slide would result in $ 9.17/kg hydrogen (no CCS).

HYDROGEN

Green Hydrogen – Current Production Costs

Lazard produces a special report on current hydrogen production costs (2021).

As can be understood from the previous slides current production costs depend very much on assumptions of costs of energy and electrolysis. Lazard did a sensitivity analysis. Following are the costs per kg of hydrogen for a 20 MW electrolyzer based on energy costs (cents/kWh) and electrolyzer capex ($/kW):

-- alkaline, energy-$0.02, capex-$690: $ 1.83/kg

-- alkaline, energy-$ 0.06, capex-$ 1050: $ 4.87/kg

-- PEM, energy-$ 0.02, capex-$ 890: $ 2.27/kg

-- PEM, energy-$0.06, capex-$ 1330: $ 5.78/kg

HYDROGEN

Green Hydrogen – Current Production Costs

Report 1 of the European Hydrogen Observatory analyzes the current hydrogen costs in Europe.

The estimate the following production costs and cost ranges:

- **Steam methane reforming: $ 6.80/kg**
- **Steam methane reforming + CCS: $ 6.95/kg**
- **Green hydrogen using grid electricity: $ 4.24-$17.92/kg**
- **Green hydrogen using a renewable source: $ 4.56 - $ 10.46/kg**

Obviously, fossil fuel-based hydrogen is more expensive in Europe than in the US due to the higher natural gas prices.

The average green hydrogen costs based on a renewable source is $ 7.48/kg, only a fraction over SMR+CCS

HYDROGEN

Green Hydrogen – Current Production Costs

The current green hydrogen conditions in Europe were also confirmed by the 2023 bid round of the European Hydrogen Bank.

The bid round related to subsidies requested by bidders to commercially sell green hydrogen.

The bids ranged from $ 0.38/kg to $ 0.48/kg.

This also indicates that green hydrogen costs in Europe are very close to the fossil fuel-based market prices.

HYDROGEN

Hydrogen – Current Market Prices

The current market prices for largely fossil fuel-based hydrogen are (as of May 2024) for large scale transactions based on the Hydrogen Pricing Report:

- **United States: $ 4.83/kg**
- **Europe: $ 7.22/kg**

Prices at H2 Mobility filling retail station based on 350 bar pressure in Germany are currently:

- **$ 9.50/kg for long term contracts**
- **$ 12.85 - $ 13.75/kg for occasional deliveries**

HYDROGEN

Green Hydrogen – Current Production Costs

-- Frontier Energy is planning the Bristol Springs Solar Project with 500 MW of solar power. The project is supposed to start in 2023.

The company claims that they will produce hydrogen for Aus $ 2.85 per kg which corresponds to US $ 1.98 per kg.

A 36.6 MW alkaline electrolyser will produce an estimated 4.4 million kg of hydrogen per year. The low cost are the results of the favorable location in Waroona, 120 km south of Perth, next to the alumina refinery.

-- A research team from the Ostrava University in Czechia has established that green hydrogen could be produced at $ 3.12/kg using excess energy used for wastewater in addition to solar and wind.

HYDROGEN

Green Hydrogen – Low-Cost Countries

The costs of producing hydrogen therefore depends much on the conditions in certain countries.

McKinsey & Company has identified Chile as country that may be able to produce green hydrogen for $ 1.40/kg by 2030 and about $ 0.50/kg by 2050 and would be potentially well placed to export hydrogen to Japan and Korea.

Other possible low-cost countries (below $ 2/kg by 2030) are Australia, South Africa, Namibia, India, China, Saudi Arabia, Libya, Egypt, Turkey, Oman, Ethiopia, Spain, Mexico and Iran.

Also, the states of the United States with low cost solar have good potential for low-cost green hydrogen.

HYDROGEN

Green Hydrogen – Production Economics

Based on the IEA Future of Hydrogen Report (2020), the cost of hydrogen through electrolysis is primarily determined by three variables:

- **the costs of the electrolyser, a costs as low as $ 350/kW is attractive.**
- **the load factor, which is how many hours per year can the electrolyser be used out of the total 8760 hours per year. A load factor of 70% or better is attractive.**
- **the cost of electricity in terms of $/MWh. Costs of less than $ 20/MWh ($0.02/kWh) are attractive.**

Under these conditions green hydrogen may be produced at $ 1.50/kg or less. So, much depends on the cost of future electrolysers and the availability of low-cost renewable energy under a high load factor.

Following is a review of a number of other projects that are underway.

This indicates that the commercial judgement is that is has become worthwhile to start producing green hydrogen

HYDROGEN

Green Hydrogen – Current Producing Project

Probably the first green hydrogen producing project in the world is the Kuqa project in Xinjiang of Sinopec.

It started producing in 2023 at a rate of 20,000 tons of green hydrogen per year based on solar and wind.

HYDROGEN

Green Hydrogen – Current Projects

The traditional way to produce hydrogen is from cheap hydropower. In 1940 NEL ASA of Norway produced already 23.5 million kg per year from its plant in Rjukan and is a leading supplier of electrolysers.

Current projects based on renewable energy are:

--Infinite Blue Energy is building a 9.1 million kg/year project in Perth, Australia, operational by 2022 based on solar and wind.

--Shell is constructing a 60,000 kg/day (21.9 million kg/year) green hydrogen plant based on wind energy in Rotterdam which will be operational by 2023. The production will be sent by pipeline for use in the Pernis refinery and for trucking.

-- Iberdrola is spending 170 million Euros to create a 14,000 tons per year facility in Felixtowe(UK) to be operational by 2026.

HYDROGEN

Green Hydrogen – Current Projects

(continued):

-- Infinite Blue Energy is also planning a large 1000 MW project for New South Wales, Australia, called "Project NEO", based on solar, and wind, producing green hydrogen.

-- Saudi Arabia started its 650 tons/day $ 5 billion NEOM project, which will be the largest hydrogen project in the world.

-- Namibia has approved the Hyphen Hydrogen Energy project to produce 2 million tons of green ammonia per year.

-- Indian firms will invest $ 16 billion in Egypt to produce 2.2 million tons of green hydrogen per year.

-- H2B2 has built a plant in California that will produce 3 ton/day in 2024.

HYDROGEN

Green Hydrogen to Ammonia – Current Projects

-- World Energy GH2 Inc. is investing in a large green ammonia export project in Stephenville in Newfoundland and Labrador called Nujio'qonic.

It consist of 3 GW of wind generation will deliver 250,000 tons per year of hydrogen based on 1.5 GW electrolysers, for the export of hydrogen and green ammonia, mainly to Germany by 2025.

Canada and Germany signed an agreement early 2024 to expand this cooperation to other players in Canada with the objective to have eventually hydrogen auctions to establish hydrogen pricing.

-- China is targeting for the end of 2024 a production of 220,000 tons/y.

-- H2 Energy Europe is planning a 1GW/90,000 tons/y green hydrogen plant in Esbjerg based on offshore wind.

HYDROGEN

Green Hydrogen – Current Large Projects

-- The largest Renewable Hub project intended to produce hydrogen and ammonia is the Western Green Energy Hub (WGEH) covering 15,000 km2 in Western Australia planning to produce 50 GW of wind and solar to produce 3.5 million tons of green hydrogen and 20 million tons of ammonia per year. The estimated cost of the project is $ 100 billion.

-- Another large project is the Total Eren Project in the Northern Territories with 2GW of solar power and 1 GW of electrolyser producing 80,000 tons per year of hydrogen.

-- Copenhagen Industry Partners (CIP) are promoting a project on South Australia's Eyre Peninsula involving 14 GW of renewable energy for hydrogen production.

HYDROGEN

Green Hydrogen – Current Large Projects

-- Oman has decided to invest in a 1 – 1.5 million tons H2 per year project in Duqm. This involves 8 – 15 GW electrolyzer capacity and 16 – 30 GW of renewable energy capacity.

Hydrogen will be used for local consumption as well as the production of methanol for export. Also, a steel plant is contemplated.

Oman hopes to expand to 7.5 – 8.5 million tons by 2050.

Oman has signed in 2023 an agreement with Zenith Energy of the Port of Rotterdam to create an export corridor for liquid green hydrogen.

HYDROGEN

Green Hydrogen – Current Large Projects

-- The Pecem Industrial and Port Complex (CIPP) is a joint venture between the Brazilian State of Ceará and the Port of Rotterdam.

The State Government signed a contract with Grupo Jepri for a $3.6 billion green hydrogen project producing 1.2 million tons of hydrogen per year in the complex.

-- The US Government has provided a $ 1.66 billion loan to Plug Power to create 6 clean hydrogen production facilities in the US.

-- It should be noted that in total the current global pipeline of hydrogen projects is gigantic. In total 1.2 TW (1,200,000 MW) is being planned, with about 32% in Europe, according to Aurora Energy Research

HYDROGEN

Green Hydrogen – Offshore Projects

The first attempts are made to produce hydrogen in the offshore where it would have direct access to wind energy.

Currently one project is under development:

-- Lhyfe (France) for a European consortium has done pilot production and is creating the HOPE project offshore Oostende, off Belgium.

RENEWABLE ENERGY DEVELOPMENTS

Offshore Projects

-- The Dutch SENSE-HUB project of TNO is considering wind, floating solar and hydrogen production in the North Sea.

HYDROGEN

Blue Hydrogen – Current Projects

-- Saudi Arabia intends to become the largest "blue" hydrogen exporter and in fact shipped its first blue hydrogen cargo.

-- Alberta also aims to become a blue hydrogen exporter. Suncor and ATCO have entered into a large blue hydrogen project with a production target of 300,000 tons per year.

-- Equinor is planning to invest in a blue hydrogen cluster in Hull, UK.

HYDROGEN

Green Hydrogen –Electrolysis-Breakthroughs-Replacing Iridium

Technical breakthroughs are possible that lower the cost of electrolysis by replacing the expensive iridium in anodes of PEM electrolyzers:

-- Rice University is replacing iridium with a nickel enhanced ruthenium oxide which resulted in a robust anode catalyst. Ruthenium oxide is relatively inexpensive.

-- Argonne National Laboratory (DOE) is replacing iridium with a low-cost anode cobalt-based catalyst.

-- The Hydrogen and Fuel Cell Research Centre of the Korean Institute of Science and Technology replaces platinum and 90% of iridium and platinum with inexpensive iron-nitride (Fe2N).

-- The RIKEN Center in Japan hopes to replace iridium largely through the use of manganese.

HYDROGEN

Green Hydrogen – Other Breakthroughs in Electrolysis

Various technical breakthroughs are possible that would lower the cost of electrolysis significantly:

-- Hysata a spinout company of the University of Wollongong has developed a new type of electrolyser that only requires 41.5 kWh of electricity per kg of hydrogen (instead of the typical 55 kWh) and is 95% efficient and could reduce hydrogen costs to $ 1.50/kg.

-- Rolls-Royce is acquiring 54% of Hoeller Electrolyser which has new electrolyser technology which claims can produce hydrogen for prices "not previously thought possible".

-- Milwaukee based Advanced Ionics, sponsored by Repsol, is using their Symbion electrolyser technology, which uses waste heat and is 50% more efficient than other processes. The goal is to produce hydrogen for less than $ 1/kg.

HYDROGEN

Green Hydrogen – Other Breakthroughs in Electrolysis (Continued):

-- Engineers at the RMIT University of Australia have demonstrated the benefit of sound waves in electrolysis.

With high frequency (10 MHz) sound waves it was possible to produce 14 times more hydrogen with 27% less energy use.

According to associate professor Amgad Rezk, it eliminates the use of corrosive electrolytes (water can be used) and expensive electrodes such as platinum or iridium; silver can be used instead.

-- Scientists at the Shenzhen University and Nanjing Tech University have developed a methodology to produce hydrogen through electrolysis directly from seawater by permitting the seawater to flow through a special membrane to the electrolyzer.

HYDROGEN

Green Hydrogen – Based on Salt Water

-- An important breakthrough is in China which achieved to produce hydrogen from sea water in Xinghua Bay based on a specially designed floating offshore platform called Dongfu No 1. The platform combines wind energy production with in-situ hydrogen electrolysis.

Normally hydrogen electrolysis requires ultra pure water. With over 90 chemical components, micro-organisms and suspended particles, seawater normally creates issues such as corrosion, toxicity, catalyst inactivation, etc.

However, the Chinese Academy of Engineering, led by Xie Heping, and the Dongfang Electric Corporation managed to overcome these difficulties by isolation and managing the influence of these factors. This may revolutionize traditional production methods.

HYDROGEN

Green Hydrogen – Future Production Costs

Future costs of green hydrogen is expected to drop, even if there are no unexpected breakthroughs in new technology.

Further R&D will result in more efficient electrolysis and optimization of the various processes. Simply scaling up and increasing the amount of electrolysis will reduce costs.

IRENA expect that the LCOH of green hydrogen by 2030 will be about $ 1.80 - $ 2.00/kg. The US DOE has established the goal of $ 2/kg by 2026 and $ 1/kg by 2031.

Siemens plans to produce hydrogen for $ 1.50/kg by 2025. BNEF estimates that the LCOH by 2050 could be in the range of $ 0.80 to $ 1.60/kg largely as a result of reduced electrolyser costs. IRENA and a recent estimate of BNEF indicates less than $ 1/kg. This would make hydrogen very competitive with natural gas in a variety of markets.

HYDROGEN

Green Hydrogen – Future Production Costs - IRENA

The cost of future hydrogen depends largely on the cost of future renewable energy production. This cost is highly dependent on the climate conditions and land availability around the world.

IRENA produced therefore a detailed survey considering this geographical variation and produced supply curves for the various countries. Assuming world hydrogen demand would be about 12% of the total world energy demand in 2050, IRENA determined the LCOH for various countries, not taking possible transportation costs into account.

They made an optimistic and pessimistic calculation for reach country. The following slide contains the results.

HYDROGEN

Green Hydrogen – Future Production Costs - IRENA

The LCOH range in US $/kg for the various countries in 2050 is:

Country:	Optimistic:	Pessimistic:
China	0.65	1.15
Chile	0.67	1.18
Morocco	0.70	1.45
Australia	0.72	1.20
India	0.76	1.40
USA	0.78	1.52
Spain	0.80	1.70
Brazil	1.00	1.90
Germany	1.10	1.75
Russia	1.12	1.78
Japan	2.35	3.30
South Korea	2.95	4.10

HYDROGEN

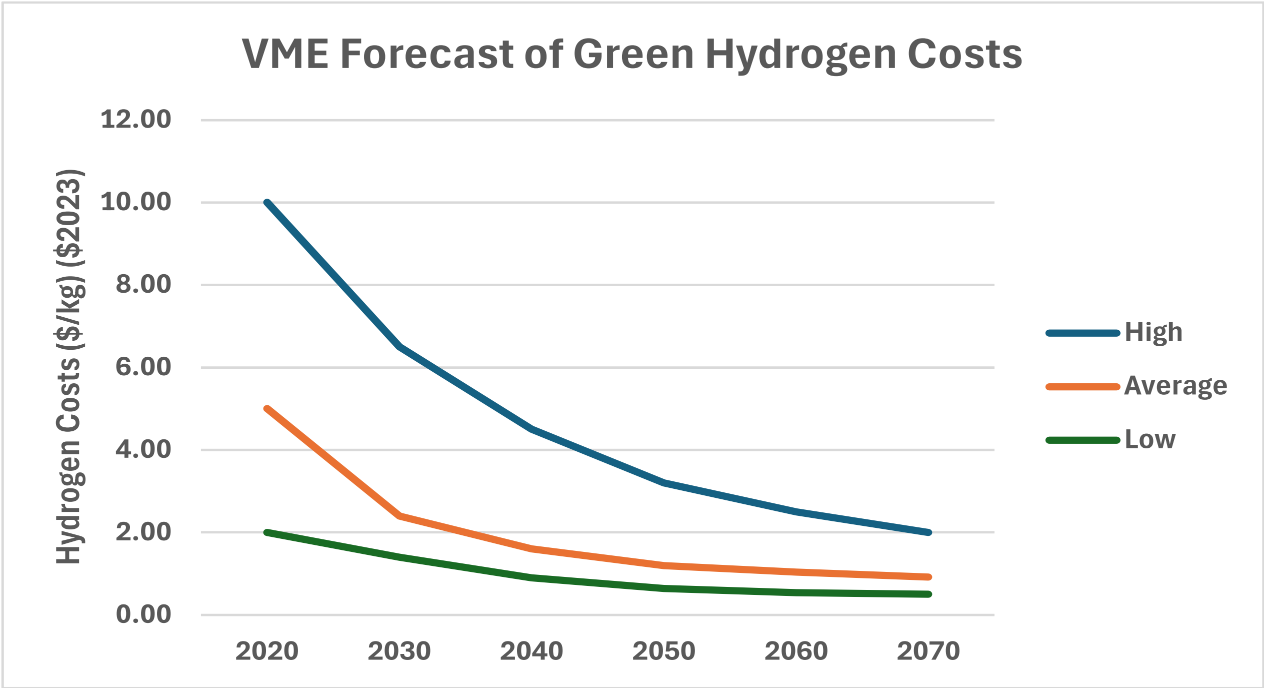
Green Hydrogen – Future Production Costs

Green Hydrogen at Source Price Forecast (US $ per kg)						
	2020	2030	2040	2050	2060	2070
High	10.00	6.50	4.50	3.20	2.50	2.00
Average	5.00	2.40	1.60	1.20	1.04	0.92
Low	2.00	1.40	0.90	0.64	0.54	0.50

The VME forecast of green hydrogen costs is based on a variety of sources. The $ 5/kg starting price is the US price, Europe is higher, and China and Middle East is lower. Green hydrogen also includes the potential SGH2 process. The Average forecast for 2030 is largely based on Bloomberg NEF, while the 2050 forecast is largely based on the IRENA estimate. The forecast is extended to 2070.

HYDROGEN

Green Hydrogen – Future Production Costs



The VME forecast in chart form of green hydrogen costs as provided in previous slide.

HYDROGEN

Green Hydrogen – Sharp drop in electrolyser costs expected

Bloomberg did a detailed analysis of future electrolyser costs carried out by Xiaoting Wang reviewing 20 companies with 30 projects. A very significant drop is expected prior to 2025, which is the basis for the expected drop in hydrogen costs. Wang expect the Chinese Alkaline as well as Western Alkaline and PEM to drop about 30%.

Cost will continue to drop sharply afterwards. Wang Expects Chinese Alkaline to drop from about $ 350/kW to $ 200/kW by 2027, Western Alkaline from $ 1200/kW to $ 200/kW by 2032 and Western PEM from $ 1400/kW to $ 200/kW by 2035.

Further reductions to about $ 100/kW by 2050 are expected.

HYDROGEN

Green Hydrogen – Project Catapult

Catapult is a UN sponsored project to increase green hydrogen production 50-fold to 25 GW based on an investment of $ 110 billion by the year 2026. The concept is that by scaling up the level of production, costs can be brought down to less than $ 2/kg. Supporting companies are:

-- ACWA Power, Saudi Arabia

-- CWP Renewables, Australia; consortium member of the Asian Green Energy Hub, the largest green hydrogen and ammonia export project in the world.

-- Envision, China

-- Iberdrola, Spain

-- Ørsted, Danemark

-- SNAM, Italy,

-- Yara International, Norway; Yara produces 8 million tons of ammonia per year and 22 million tons of fertilizers.

HYDROGEN

Green Hydrogen – Project Hydeal Ambition

The Hydeal Ambition project is an industry organization of 30 companies involved in hydrogen, with a goal to produce hydrogen at $ 1.80 per kg by 2030. This price would include production, storage and transportation.

The ambition is to construct 95 GW of solar and 67 GW of electrolysis with the capacity to produce 3.6 million tons of green hydrogen per year.

HYDROGEN

Hydrogen – Energy Earthshots

The US Department of Energy announced one of the Energy Earthshot programs: the Hydrogen Shot.

This program is to support R&D and development of hydrogen production in order to bring the cost down below $ 1/kg by 2030.

The program launched the RFI (request for information) about programs that may qualify.

Most observers consider the $ 1/kg by 2030 an unachievable goal.

HYDROGEN

Green Hydrogen – H2Pro

H2Pro a company backed by Breakthrough Energy Ventures ("BEV"), a company owned by Bill Gates, is claiming the possibility for producing hydrogen at $ 1 per KG.

This is based on its E-TAC ("electrochemical – thermally activated chemical") system. As with electrolysis this process produces hydrogen and oxygen based on water with electricity. However, rather than a one-step process requiring a membrane, it is a two-step process that does not require a membrane, significantly simplifying the process and lowering the costs. The E-TAC system is unique since it is both electrically and chemically driven.

BEV is partnering with the EU Horizon 2020 program in order to support this project.

HYDROGEN

Green Hydrogen – Rolls-Royce

Rolls-Royce is taking a 54% share in Hoeller Electrolyser.

This is a company developing new technology for polymer electrolyte membrane (PEM) stacks for cost effective production of hydrogen.

The concept is to produce hydrogen at costs not previously thought possible. An initial customer project is planned for 2024.

HYDROGEN

Storage

Hydrogen can be stored in various ways. The main advantage is that the gravimetric density is very high at 120 MJ/kg (compared to 44 MJ/kg for gasoline, but the volumetric density is very low at about 8 MJ/liter (as liquid)(compared to 32 MJ/liter for gasoline). Typical physical storage consists of:

-- storage in high pressure tanks at 350 – 700 bar. For instance, this is done in the hydrogen project in French Guiana.

-- cryogenic storage as a liquid at minus 252.8 degrees Celsius.

-- in salt caverns, where it can be stored indefinitely until used, for instance for grid balancing purposes or industrial use. The Chevron Phillips Clemens Terminal in Texas has stored hydrogen since the 1980's. The capacity is 2,520 metric tons of hydrogen.

HYDROGEN

Storage

There are also several other ways to store hydrogen:

-- it can be stored as a liquid in a Liquid Organic Hydrogen Carrier (LOHC). The organic carrier is, for instance, dibenzyltoluene or a variety of other carriers. It can store 57 kg of hydrogen per cubic meter of LOHC. The uptake of hydrogen is an exothermic process. It can be stored under a broad temperature range and atmospheric pressure. It can be transported as any liquid. The release of hydrogen is an endothermic process at 300 degrees Celsius. A German company, Hydrogenious LOHC Technologies, has the largest storage plant at CHEMPARK, Dormagen, Germany.

HYDROGEN

Storage

(continued:)

-- sorbent storage materials. The advantage of these materials it that is absorbs and desorbs H_2 without change to the molecule. The disadvantage is that absorption capacity is relatively weak. Sorbents could be coordination polymers or activated carbons.

-- metal hydrides. Metal hydrides can be used for a variety of applications such as thermal storage or heat pumps.

Research on a variety of these storage methods will improve the ability of hydrogen to play a role in the transport or other sectors.

HYDROGEN

Transport

Hydrogen can be transported in a variety of ways:

-- by pipelines. These pipelines are essentially no different from current pipelines for natural gas. The European Industry Association "European Hydrogen Backbone (EHB)" proposed in 2021 in total 11,600 km for 2030 and 39,700 km by 2040, shipping hydrogen among 21 countries. However, for 100% H2 transport, pipelines need to be repurposed, as discussed in the next slide.

-- by liquified hydrogen carrier. The "Suiso Frontier" a ship of Kawasaki Heavy Industries, Japan, has picked up its first cargo of liquified hydrogen in 2022 in Australia for transport back to Japan.

-- by "tube trailer", which is essentially a truck with a stack of high-pressure compressed gas tubes at 180 bar pressure.

-- by LOHC truck.

HYDROGEN

Transport

Existing natural gas pipelines can be repurposed for the transport of hydrogen at about 20% of the costs of constructing a new hydrogen pipeline.

Hydrogen per volume content contains only 1/3 of the energy of methane. However, the transport velocity in a pipeline is about three times that of methane, so in general the same amount of energy can be transported.

However, this requires considerable additional compressors. Also, other fittings and facilities of the pipeline need to be replaced. Also much depends on the quality of the steel. There is a "brittleness" problem due to lose hydrogen atoms entering the steel structure. However, this can also be dealt with based on frequent pig surveys.

HYDROGEN

Transport – German hydrogen pipeline network

The current German government has provided significant financial guarantees for the construction of a 9700 km hydrogen pipeline network in Germany, with 60% existing gas lines being part of the network. The pipeline system would be completed by 2037.

The costs are estimated to be about $ 21.6 billion.

HYDROGEN

Transport – Algeria - Europe

Transporting an energy amount in the form of hydrogen is much cheaper than electricity through an electricity network.

Large hydrogen pipeline projects are currently contemplated. A large project is the 3,300 km SoutH2 Corridor Project connecting Algeria with Europe.

The line will start in Hassi R'Mel and via Sfax in Tunisia will cross the Mediterranean to Italy and from there onwards to Austria and Germany. 70% of the line will be repurposed existing gas lines. It is expected to be fully operational in 2030 with a capacity of 4 million tons of hydrogen.

It will be constructed by a consortium led by Snam S.p.A. (Italy).

Algeria aims to supply 10% of European hydrogen needs by 2040.

HYDROGEN

Transport – Ceará – Rotterdam- as ammonia

The Port of Rotterdam invested 30% in a joint port facility in Pecém in Ceará, Brazil, with the potential to ship large volumes of hydrogen from Brazil to Rotterdam.

The rationale for the investment is that Rotterdam want to become the main importing hydrogen port in Europe because:

- **Brazil is anticipated to produce the lowest cost hydrogen in the world – estimated to be as low at $ 0.55/kg by 2050.**
- **Transport cost of hydrogen to Rotterdam are the lowest from Ceará compared to any other port at $ 2.88/kg hydrogen.**
- **The huge solar potential of the Ceará of 643 GW providing a limitless resource.**
- **Ceará export forecast: 750,000 tons per year in 2030.**

HYDROGEN

Electriq Powder

Electriq is a powder that contains hydrogen in a chemical composition. Hydrogen can be easily removed from the powder.

Electriq and Zenith Terminals have signed an MOU to start producing the powder in a plant in the Netherlands.

It works as a coffee machine.

The powder is inert and non-flammable.

It can be controlled on demand with a simple release system.

This means this could be a highly efficient way to store and transport hydrogen, if further commercial results prove this value.

HYDROGEN

Blue Hydrogen Transport

Norway and Germany are planning to build a 10 GW blue hydrogen pipeline by the end of this decade.

The project is developed by Equinor and RWE. It involves large scale carbon capture and storage of CO2 in North Sea petroleum reservoirs.

Over time they hope to convert to green hydrogen.

HYDROGEN

Transport R&D

Research is going on with respect to hydrogen transport:

-- Korea Electric Power Corp have developed a liquid organic hydrogen carrier that could concentrate hydrogen in a liquid in much smaller volumes.

HYDROGEN

Use of Hydrogen to Generate Energy

Hydrogen is important because of its versatility to replace fossil fuels in a wide range of applications.

Hydrogen can be burned directly as fuel such as natural gas or gasoline, diesel or fuel oil and create heat, electricity or energy or used in fuel cells to create electricity based on chemical reactions.

Hydrogen can be used in an internal combustion engine and is actually somewhat more efficient than gasoline and does not produce any air pollutants.

Gas turbines for power generation can be run on a mixture of hydrogen and natural gas or on pure hydrogen.

Jet engines in aircraft can use hydrogen, which has an energy density of 3 times jetfuel in terms of mass but has a lower energy density per unit of volume.

HYDROGEN

Use of Hydrogen to Generate Energy

For many applications, however, hydrogen produces electricity by way of fuel cells.

There is a wide variety of fuel cells with different characteristics. Fuel cells generate electricity based on a chemical reaction. In a typical fuel cell, hydrogen is fed to the anode and oxygen to the cathode and the fuel cell produces electricity and water based on catalysts. Electrons move from the anode to the cathode and hydrogen protons move through an electrolyte to the cathode to combine into water. A great advantage of fuel cells is that they do not produce sulfur or nitrogen oxides, only clean water.

HYDROGEN

Use of Hydrogen – Types of fuel cells

There are the following types of fuel cells:

-- Alkali Fuel Cells (AFC) - Operate with compressed pure hydrogen and oxygen and a potassium hydroxide water solution as electrolyte. The operate at 150 – 200 Degrees Celsius and produce 300W to 5 kW of power with a 60% efficiency. The platinum electrode catalysts are expensive. Typical Use is for Back-Up Power. It is also used in space vehicles.

AFC Energy has developed a hydrogen-based AFC system to charge EVs. It is in particular suitable in remote locations.

GenCell Energy has developed an AFC that operates in conjunction with the Enapter EAM Electrolyzer in order to generate hydrogen when renewable energy is in excess and generate electricity at electricity shortage as a single overall system.

HYDROGEN

Use of Hydrogen – Types of fuel cells

(continued):

-- Molten Carbonate Fuel Cells (MCFC) – use high temperature salt carbonate compounds. Operating temperature is 650 degrees Celsius at 60%-80% efficiency. Units of 2 MW to 100 MW are possible. They are based on cheaper nickel electrodes, but are more complex to operate than AFCs. Typically used for stationary power generation; in total over 300 MW installed.

MCFCs can be used with various fuels such as methane, biogas or hydrogen. Fuels deliver hydrogen directly due to high temperatures.

HYDROGEN

Use of Hydrogen – Types of fuel cells

(continued):

-- Phosphoric Acid Fuel Cells (PAFC) – Use phosphoric acids as electrolite. Operating temperature is 150 – 200 degrees Celsius. Efficiency is 40 – 80%. Units of 200 kW to 11 MW have been constructed (lately a 50 MW plants was built). Platinum electrode catalysts are needed. Typically used for stationary power generation.

The Doosan PureCell Model PAFC delivers 440 kW of power based on natural gas or hydrogen. Doosan has 758 units (330 MW) in operation and 398 units (177 MW) are being installed.

HYDROGEN

Use of Hydrogen – Types of fuel cells

(continued):

-- Proton Exchange Membranes (PEM) Fuel Cells– work with a polymer electrolyte in the form of a sheet. Efficiency is 40 – 50%. The operate at 80 degrees Celsius. Units are typically of 50 to 250 kW. The low temperature makes them suitable for homes and cars. However, fuels must be purified and platinum catalysts are used on both anodes.

Nedstack produces PEMFCs in the 7 to 13 kW range for a wide range of applications in buildings, stationary power, ships, buses, etc.

The Toyota Mirai has a PEM fuel cell stack of 114kW.

HYDROGEN

Use of Hydrogen – Types of fuel cells

(continued):

-- Solid Oxide Fuel Cells (SOFC) – Use hard ceramic metal oxides as electrolyte. Efficiency is about 60% and operating temperature 1000 degrees Celsius. Cell Output is 100 kW. Can use a variety of fuels. Sometimes waste heat can be recycled. Typically used for stationary power generation. Suitable for combined cycle power generation.

Doosen Fuel Cell will install a prototype SOFC in a chemical marine tanker based on Ceres Power Holdings technology.

Mitsubishi Power has installed several hybrid SOFC units suitable for large office buildings, hospitals or microgrids to supply electricity and heat.

SouthernCalifornia Gas has installed two SOFCs for its facilities in order to balance solar power development.

HYDROGEN

Use of Hydrogen – Types of fuel cells

(continued):

Bloom Energy (USA) has already 900 SOFC units installed exceeding in total 500 MW. Typically current their SOFCs are 75kW. There "AlwaysOn Microgrids" have helped overcome 1500 power outages in California.

An interesting characteristic is that some fuel cells are reversible. A SOFC is reversible as Solid Oxide Electrolysis Cells. During hours of low cost or excess power they can turn electricity in hydrogen. During peak hours the hydrogen can produce electricity with the same piece of equipment. For instance, a unit supplied by Sunfire GmbH to the US Navy produces 43m3/hour hydrogen in the electrolysis mode with 85% efficiency and produces 50 KW of power at 60% efficiency in the fuel cell mode. Some PEM fuel cells are also reversible.

HYDROGEN

Use of Hydrogen – Types of fuel cells-Future Costs

Honda is planning an all new Fuel Cell Electric Vehicle (FCEV) for its CR-V 5 seater SUV next year. In cooperation with General Motors, Honda believes that the costs of fuel cells can be reduced by 50% towards 2030.

HYDROGEN

Use of Hydrogen – Fuel Cell for Aviation

Universal Hydrogen has successfully tested a 1 MW fuel cell for aviation based on liquid hydrogen.

Two modules operating a three hours with 200 kg of liquid hydrogen each could give a typical regional airliner such as an ATR72 a range of 500 nautical miles.

HYDROGEN

Anticipated market developments

The market development of hydrogen is anticipated to be the following:

- **Until 2027: Ammonia for fertilizers, hydrogen for refining, methanol production and heavy truck transportation.**
- **Until about 2035: Synthetic fuel development, steel industries, other manufacturing and rail and ship transport.**
- **Until about 2050: Backup power generation, district heating, natural gas grid blending and high temperature industrial uses.**

It should be noted that TotalEnergies signed with Air Products a 15 year agreement for 70,000 tons/y for its refineries in Europe.

Mangalore Refinery and Petrochemicals has started the bidding for a 25 year contract for 10 Ktpa of green hydrogen.

HYDROGEN

Long term Hydrogen Market Forecast

Under "Revolution # 3" under "Impacts on the Petroleum Industry" a wide range of uses of hydrogen will be discussed.

Any forecast of the long-term hydrogen market is still rather speculative.

The main market would be the transport market for heavy duty and other vehicles and possible other transport, such as aviation. However, other important markets would be heating of buildings, industrial feedstock, industrial energy and power generation.

The 2022 IEA estimates are that the hydrogen market will expand from about 95 million tons of largely grey hydrogen, to 180 million tons by 2030 consisting of 70 green, 20 blue and 90 grey, and to 470 million tons by 2050, consisting of 330 green, 130 blue and 10 grey.

HYDROGEN

Africa's supply potential

Africa could supply as much as 10% of the world hydrogen production in 2050 due to its excellent solar and wind potential according to McKinsey&Company and supported by Masdar.

Africa could be a low-cost producer. It would help to supply the needs of Europe because of its proximity and the local African needs.

A production rate of between 30 to 60 million tons per year is possible of which 10 – 20 million tons would be for local demand. Electricity requirements would be between 1500 and 3000 terawatthours (TWh).

It could create 3.7 million jobs and add $ 120 billion to the GDP.

HYDROGEN

Hydrogen Leakage

A possible serious downside of hydrogen is the potential for hydrogen leakage in the atmosphere.

Scientists estimate that if 10% of the hydrogen produced and used would leak in the atmosphere, the benefit of using hydrogen versus fossil fuels would be largely eliminated.

This is due to the fact that hydrogen would thin the atmosphere and interfere with the molecules that otherwise would help to destroy the greenhouse gases already there.

Information about hydrogen leakage is insufficient according to Anne-Sophie Corbeau from the Columbia University center of Global Energy Policy.

GREEN AMMONIA

Use in Energy Transition

Ammonia has a great potential to play a major role in the energy transition. It is easy to produce from green hydrogen and it is easy to store and transport with large scale facilities already in place, also as an alternative to direct hydrogen transportation.

The production from green hydrogen consist of integrating the green hydrogen production with the production of ammonia based on the Haber-Bosch process. Since the Haber-Bosch process requires a continuous operation, green hydrogen must be stored after possible irregular production.

Ammonia can be liquefied at minus 33 Celsius. This creates a volumetric hydrogen content that is higher than compressed hydrogen.

GREEN AMMONIA

Use in Energy Transition

Ammonia is not an adequate direct fuel source.

However, ammonia can be cracked to produce hydrogen and nitrogen. This is known as “Spaltgas” and can be used as fuel. This gas can be used to produce bricks for instance.

Ammonia can also be converted to hydrogen right at a filling station, making it suitable for a role in hydrogen-based transportation.

Ammonia can also be mixed with a fuel, such as gasoline or butane. A variety of ammonia-fuel mixtures can be directly used in direct combustion engines.

Ammonia can be used in a diesel engine instead of diesel by adding a spark ignition system.

GREEN AMMONIA

Use in Energy Transition

The negative aspects of using ammonia directly as a fuel are:

- **Ammonia releases large amounts of nitrogen-oxides. These are in turn a potent greenhouse gas 300 times more potent than CO2 and therefore even if green hydrogen is used, the direct burning of ammonia results in a negative impact on the atmosphere.**
- **Ammonia is highly toxic and corrosive. High quantities of ammonia in the air can result in blindness, lung damage or death.**

GREEN AMMONIA

Projects

A wide variety of green ammonia projects is already being planned or in execution.

An example is the Phase-I green ammonia plant of the Indian company ACME in Oman.

Yara, a Norwegian ammonia trading company, has signed a 100,000 tons per annum contract with ACME for first delivery by 2027 complying with the EU Renewable Energy Directive.

ACME hopes to expand the Oman plant to 900,000 tons per annum. ACME built its first green ammonia plant in Bikaner, Rajasthan, India in 2021.

GREEN AMMONIA

Projects

Another example is the Sonangol project in Angola.

The project will be built at the Barra do Dande Ocean Terminal of Sonangol using 400 MW of a nearby existing hydropower project.

The green ammonia will be exported to Germany from 2024 onwards.

The aim is to sell 280,000 tons of green ammonia to Hintco under the German H2Global green hydrogen program under a ten-year contract.

GREEN AMMONIA

Direct Ammonia Synthesis

Research is being done on the direct synthesis of ammonia without having to use green hydrogen.

Australian Researchers from the UNSW School of Chemical Engineering and the University of Sydney are developing a process whereby creating a plasma using renewable energy, a mixture of nitrogen oxides can be created which can be converted directly in ammonia.

The breakthrough is in using these plasmas is combination with electrochemistry.

It opens the door to produce ammonia directly on a small scale and at room temperature. This means farmers could produce their own fertilizers.

GREEN AMMONIA

Ammonia Fuel Blend

The UK Sunborne Systems has developed a reactor whereby liquid ammonia can be transformed in a fuel blend of hydrogen, nitrogen and uncracked ammonia.

This fuel blend can be used in Internal Combustion Engines of light vehicles and other light engines.

It is anticipated that further development can apply the fuel to larger industrial engines and gas turbines.

This would create a possibility to accelerate energy transition.

E-METHANOL

From Green Hydrogen

The Danish company Oersted is building the largest commercial production facility for carbon-neutral marine fuel in NE Sweden.

The 70 MW electrolyzers are based on Siemens proton exchange membrane (PEM).

The plant is expected to produce 50,000 tons of e-methanol per year from renewable energy and biogenic carbon dioxide from 2025 onwards.

The e-methanol is a CO2 neutral fuel that is easy to store and transport and is used for marine transport.

E-METHANOL

From Green Hydrogen

-- A large wind power to methanol project is being done by the China General Nuclear Power Corporation in Inner Mongolia.

The total investment will be about $ 2.25 billion.

The output consists of 107,900 tons of hydrogen and 800,000 tons of methanol per year.

-- OCI Global, a large producer of green methanol, announced in April 2024 that it will double its capacity in Beaumont, Texas to 400,000 metric tons per year.

E-METHANOL

For distribution

Methanol, instead of ammonia, can also be used to produce hydrogen at refueling stations to provide hydrogen for road transport.

CPCC (Sinopec) has created the first methanol to hydrogen and hydrogen refueling station in Dalian, China.

The integrated process can create 1,000 kg of hydrogen per day with a purity of 99.999%.

The station covers only a small area, compared to compressed hydrogen.

E-DIESEL

-- VTT and partners in Finland have for the first-time developed E-diesel from green hydrogen and CO2 based on Fisher-Tropsch synthesis. The tested it on a tractor in Nokia. New methods are more efficient than before. The product is high quality and can be used on existing diesel engines. There is potential for large scale production.

-- Mr. Young Kim of the Korean Institute of Machinery and Materials has achieved a breakthrough in developing a highly efficient microchannel reactor for producing e-diesel with acceptable cetane index. It requires 70% less catalysts with a 30 times capacity increase, converting 93% of the syngas (hydrogen and CO2) into fuel. The reactor fits in a standard cargo container, which could lead to eco-friendly fuel stations.

SYNFUELS GENERAL

Synhelion, a subsidiary of ETH Zurich is planning a plant near Cologne, called DAWN.

It is a 20 meter high tower surrounded by mirrors to concentrate solar rays. The heat is used to produce synthetic liquid fuel.

The syncrude will be send to refineries for certified processing.

The plant intends to make solar kerosene for aviation, solar gasoline and solar diesel.

SYNTHETIC POLYESTER

A first complete value chain has been created for producing synthetic polyester.

Chiyoda and others will produce p-Xylene entirely from renewable hydrogen and CO2.

This will be turned into Purified Terephthalic Acid (PTA)

This is then the basis for polyester, to make polyester fibers which will be used by Goldwin for clothing for the THE NORTH FACE brand.

CARBON CAPTURE AND STORAGE

Forests

Burning down the forest to create agricultural land, in particular in the rainforest is a major source of CO_2 emissions and therefore global warming. It is therefore important to protect the forests.

It is often argued that planting trees is a method of carbon capture and storage. Certainly, any vegetation captures CO_2 during their growth. It is estimated that the US forests capture currently 150 million tons of CO_2 (11% of US emissions)

However, once vegetation dies and decomposes the CO_2 is released. Once forests grow older, they may become emitters of CO_2. A US Department of Agriculture report estimates that by 2070 the US forests may emit as much as 100 million tons of CO_2.

Therefore, planting trees is not a permanent solution.

CARBON CAPTURE AND STORAGE

Variety of methods – Carbon Capture

There is a wide variety of methods related to Carbon Capture and Storage ("CCS"):

-- Post-Combustion technologies: there are at least 18 different post-combustion technologies which remove CO_2 from the flue gases associated with the burning of the fossil fuels,

-- Pre-Combustion technologies: there are 5 different technologies where coal, oil products or gas are first converted to CO_2 and Hydrogen, the CO_2 is removed and stored, and the hydrogen is burned.

-- Oxy-combustion: there are 5 different technologies whereby the flue gases are recycled with oxygen for the subsequent burning of fuels, thereby increasing the CO_2 content and make it more economic to recover the CO_2

CARBON CAPTURE AND STORAGE

Variety of Methods – Carbon Capture

(continued)

-- Solid Looping Technologies: there are 10 different processes, whereby flue gases are fed over calcium lime (CaO) and the resulting product is subject to a calcination reaction, creating almost pure CO2 that can be stored; in fact one of the processes can be integrated with cement production.

-- A Canadian company called Carbon Engineering, backed by Bill Gates, captures CO2 directly with machines from the air for storing or to produce synthetic fuels together with hydrogen.

CARBON CAPTURE AND STORAGE

Variety of Methods-Combustion with Oxygen

(continued):

A way to facilitate the carbon capture during combustion is the system promoted by Net Power. This company has a 50 MWth facility in La Porte, Texas, whereby natural gas is directly burned with oxygen rather than air.

This results in the creation of pure CO2, which in turn is further used in supercritical state to generate electricity in the gas turbine.

Any excess CO2 can be easily collected for sequestration.

The economics of the system still require more detail.

CARBON CAPTURE AND STORAGE

Variety of methods – Carbon Capture

(continued)

--AspiraDAC in Australia uses MOF and solar energy to remove CO_2 from the air. They are constructing a 1 ton per day DAC demonstration plant, with the ultimate goal of removing CO_2 for less than $ 20 per ton.

-- Enhanced Rock Weathering: Sheffield University is working with powdered basalt scattered over the soil, which is a good fertilizer and increases the amount of CO_2 that can be captured by the soil about 4 times. Another method is to crush olivine and spread the powder. It absorbs CO_2 very quickly through weathering.

-- there is a wide variety of other relatively low-cost bioenergy-based processes, such as processes based on charcoal.

CARBON CAPTURE AND STORAGE

Variety of methods – Carbon Capiture

(continued)

-- Tokyo Metropolitain University uses a liquid with a new compound called isophorone diamine which they claim is 99% efficient in removing CO_2 directly from the air. The CO_2 is captured and is released at 60 degrees Celsius for storage.

-- The University of Waterloo has developed a cheap process to convert CO_2 into CO based on the electrolysis of CO_2 using water and electricity. The CO in turn can be used to produce ethanol or other substances.

-- Tata Chemical Europe installed that largest carbon capture and usage plant, capturing 40,000 tons per year of CO_2 and turning it into sodium bicarbonate.

CARBON CAPTURE AND STORAGE

Variety of methods - Carbon Capture

(continued)

-- The Pacific Northwest National Laboratory (PNNL) of DOE (US) have developed a special solvent that captures CO2 from flue gases and subsequently converts the CO2 into methanol. They claim the costs will be $ 39/ton.

-- Other importance processes are BECCS and DAC to be discussed in the following slides.

CARBON CAPTURE AND STORAGE

Variety of Methods – Carbon Capture (MOFs)

An area of intense research are metal-organic frameworks ("MOF"), which are specially designed materials that can take water or certain gases out of the air. The National Institute of Standards and Technology, US, has developed a promising MOF in the form of Aluminium formate. It is simple, stable and very low cost.

BASF has become the first company to produce MOFs on a commercial scale of several hundred tons per year. The client is Svante Technologies Inc. The collaboration with Svante may result in a significant reduction of CO2 emissions for a variety of industries such as hydrogen, pulp and paper, ce4ment, ste3el, aluminum and chemicals.

ExxonMobil, the Berkely University of California and the Lawrence Berkely National Laboratory nave developed a MOF called tetraamine functionalized MOF that is six times more effective and requires less energy than conventional technology and can be done under low temperatures.

CARBON CAPTURE AND STORAGE

CCS Projects – Northern Lights

An example of a CCS projects under construction is the Northern Lights project in Norway by Equinor and partners. This project contemplates the following:

1. CO2 will be captured from a cement plant and various other plants and temporary stored.

2. The CO2 will be liquefied and transported by CO2 tanker to the west coast of Norway

3. From there the CO2 gas will be transported by pipeline to a well south of the Troll Vest field, and

4. The 31/5-7 Eos well will inject the CO2 in a reservoir below the Troll formations with an effective seal.

CARBON CAPTURE AND STORAGE

CCS Projects – Bayu-Undan

An example of a CCS projects in the FEED face is the Bayu-Undan project in Timor Leste to be developed by Santos. This project contemplates the following:

1. CO2 will be captured from various sources in Darwin (Northern Australia) and compressed and dehydrated.

2. CO2 will also be stripped from the high-CO2 gas of the Barossa field at the LNG facility.

3. From there the CO2 gas will be transported by 120 km pipeline to the Bayu-Undan field and injected in its reservoirs.

It is estimated that the project will reinject 10 million tons of CO2 per year. It will be an attractive long-term employment opportunity for Timor Leste.

CARBON CAPTURE AND STORAGE

CCS Projects – Port of Rotterdam

The Porthos project of the port of Rotterdam is the largest project in Europe. It will reduce CO2 emissions of the port by 10% and will become operational in 2026.

It is a partnership between EBN, Gasunie and the Port of Rotterdam and will cost more than $ 1.3 billion.

The storage capacity will be used by Shell, ExxonMobil, Air Liquide and Air Products. The CO2 will be stored in a depleted gas field 12 miles from shore and 2 miles under the seabed. Storage of 2.5 million tons per year is contemplated over 15 years.

CARBON CAPTURE AND STORAGE

Carbon Capture Costs

A recent report done by Ray McKaskle on 5 power plants in Macon County indicated that the capture, compression and transportation was on average US $ 21 – US $ 154 per ton.

This range corresponds to a typical average for power plants of US $ 55 per ton.

The capture cost range depends on the concentration of CO2 in the effluent gas and other factors.

It is the US DOE objective to bring capture costs in regular power plants down to US $ 35 per ton.

CARBON CAPTURE AND STORAGE

CCS Costs

CCS costs remain rather high.

A review of costs related to CCS for Canadian Oil Sands indicated a cost of US $ 63 - $ 103 per ton CO2 captured and stored.

The costs of the Northern Lights project are $ 48 per ton CO2.

This equates to:

- **Canada: $ 28 – 46 per barrel equivalent**
- **Northern Lights: $ 21 per barrel equivalent**

CARBON CAPTURE AND STORAGE

CCS Projects –Exploration Permit

-- Equinor received the first CCS exploration permit in Denmark, together with Orsted and Norsøfonden.

It relates to the Kalundborg CO_2 storage project which is 1400 m underground and has a capacity of 12 million tons. The permit is to evaluate whether CO_2 can be safely stored.

-- Chevron received a Greenhouse Gas Assessment Permit offshore Australia of 8,467 sq km in a water depth of 50 – 1100 meter. It will be part of the assessment of a hub.

CARBON CAPTURE AND STORAGE

BECCS

The BioEnergy Carbon Capture and Storage (BECCS) consist of growing trees or agricultural products or use agricultural waste and

-- Producing synthetic fuels, or

-- Electricity or heat, and

Capturing and storing the CO_2 that is being released in the process.

This creates a carbon negative process. Plants remove CO_2 from the air, while the CO_2 produced during combustion is stored. This means CO_2 is permanently removed from the air.

It is generally accepted that BECCS is an essential component of reaching net-Zero. Therefore, BECCS should be promoted.

CARBON CAPTURE AND STORAGE

BECCS

The technologies used in BECCS are generally mature.

However, in order to have a meaningful impact on climate change BECCS operations must be large in scale.

This in turn creates problems with availability of land, water and fertilizer and environmental impact of large-scale agricultural operations. Also, costs are still high, up to $ 15 - $ 400 per ton CO2 recovered. The cheapest projects are bioethanol projects.

Therefore, currently projects are limited.

It is our opinion that plantations based on the very fast-growing Japanese empress tree (*Paulownia tomentosa)* should be considered. They grow up to 6 meters high in the first year.

CARBON CAPTURE AND STORAGE

BECCS-Projects

A large-scale BECCS facility is the Illinois Industries CCS facility that captures 1 million tons of CO2 per year. Owned by Archer Daniels Midland it produces ethanol from corn and stores the fermentation CO2 in geological formations underneath the plant.

Toshiba has the largest BECCS power plant a 50 MW plant in Mikawa, fueled primarily with palm kernels that recovers 500 tons per day of CO2.

A Chevron consortium is considering a BECCS facility in Mendota, California, based on agricultural waste converted to renewable synthesis gas, and 300,000 tons per year of CO2 will be stored in geological formations.

CARBON CAPTURE AND STORAGE

BECCS-Projects

Microsoft will purchase 2.76 million tons of carbon removal credits from two heat and power plants in Denmark: the woodchip Asnaes powerplant and the straw-fired boiler of the Avedoere power station, from Oersted in an 11-year deal. From 2026 onwards the two units are expected to capture and store 430,000 tons of CO_2 per year.

The capture will be based on Norway's Aker Carbon Capture technology and the CO_2 will be stored in the Northern Lights project, creating a BECCS project.

Microsoft intends to become carbon negative by 2030.

CARBON CAPTURE AND STORAGE

BECCS-Projects

NorthStar Clean Energy is planning to convert its 75MW TES File City Station power plant to burning biomass and capturing the CO2.

The plant is currently burning coal and waste.

The CO2 will be captured with Babcock & Wilcox unique SolveBright post-combustion scrubbing process.

The plant will be capable of capturing 550,000 tons of CO2 per year which will be permanently stored underground.

CARBON CAPTURE AND STORAGE

BECCS-Biochar

A very simple method to create bioenergy carbon capture and storage has been developed by Iowa State University. This consists of taking biomass and apply pyrolysis which means heating it without oxygen access. This turns the biomass into:

-- Charcoal,

-- Bio-Oil, and

-- Syngas,

and takes carbon out of the air.

-- The charcoal can be added to the soil in order to permanently bury the charcoal. It is a good fertilizer. In this way the CO2 is permanently removed from the air. A pilot project is removing 1000 tons of CO2 from the air.

CARBON CAPTURE AND STORAGE

BECCS-Biochar

(continued): It is our opinion that plantations based on the very fast-growing Japanese empress tree (*Paulownia tomentosa)* should be considered for this process. They grow up to 6 meters high in the first year. Of course, charcoal can also be burned, but in this case, there is no BECCS effect.

-- The Bio-Oil could be further separate in a tar like substance and wood vinegar with a simple sedimentation process. The tar like substance can simply be used on pathways. The wood vinegar can be used for many purposes such as an herbicide, fertilizer, insect repellent or to enhance crop performance by preventing insect activity on leaves.

-- Syngas can be used to generate electricity

CARBON CAPTURE AND STORAGE

BECCS-Biochar

(continued):

A very cheap BECCS kiln is developed by Carbonzero Sagl a Swiss company.

It consists of a typical oil barrel contained in a brick pyrolizer kiln. It can be loaded with wood branches. Optimal temperature is 470 degrees Celsius. It produces primarily oxygen rich charcoal. This can be added as soil fertilizer. Total costs of the kiln about $ 5000.

CARBON CAPTURE AND STORAGE

BECCS-Biochar – Exomad Green

The first commercial scale plant producing biochar for carbon capture and storage is the Exomad Green plant about 200 km NW of Santa Cruz in Bolivia.

Microsoft signed one of the largest Biochar Carbon Removal deals with this company involving an offtake agreement of 32,000 tons of CO2.

Exomad Green converts 300,000 tons per year of forest waste products into 90,000 tons per year carbon-based fertilizer, called Tecnochar, in the process removing 225,000 tons CO2 per year.

CARBON CAPTURE AND STORAGE

Brilliant Planet – dried algae

Brilliant Planet is involved in dried algae in Morocco.

The project consists of a laboratory and green house that creates in seawater a so-called algae bloom. Once in process the algae are transferred to ocean water containing ponds where growth continuous.

Subsequently, algae are filtered out of the water and dried and buried in salty dry conditions under the Sahara sand. Presumably, the algae remain in dried condition for thousands of years.

The retail price for small investors is $ 265/ton CO2.

Block purchased 1500 tons, presumably at a discount to the retail price.

CARBON CAPTURE AND STORAGE

DAC

Direct Air Capture ("DAC") projects are also in their infancy.

The largest current project is the Orca project in Iceland, promoted by Climeworks. A plant captures 4000 tons of CO2 per year directly from the air. After that the CO2 is injected with water in basaltic formations underground where it undergoes a natural mineralization process to remove the CO2 permanently from the air. The energy for the plant is based on renewable geothermal energy. The costs are \$ 600 - \$ 800 per ton and the company sells offset packages for \$ 1200 per ton.

If costs can be brough down and operations can be scaled up, there is a possibility for 1 million tons per year by 2030.

CARBON CAPTURE AND STORAGE

DAC Project

A possible first commercial project is the project in Notrees, Texas, to be carried out 1PointFive, a division of Occidental Petroleum, and Carbon Engineering, a Canadian tech company after a successful FEED study.

When fully operational the project will capture 500,000 tons per year, and this will be injected in geological formations to be operated by 75 people. The costs are estimated to be between $ 94 and $ 232 per ton.

The recent US Inflation Reduction Act, provides a tax credit of $ 85 per ton stored.

1PointFive has announced a scenario of constructing 70 DAC facilities worldwide by 2035 and could license up to 1000 of such projects.

CARBON CAPTURE AND STORAGE

DAC using trains

A study team of the University of Toronto, including Geoffrey Ozin of the solar fuels group, has designed a DAC system using trains.

The advantage is that in this case the costs of the large fans and related energy as well as the land occupancy is eliminated.

They estimate that specially equipped train wagons could capture 6000 tons CO2 per year at a cost of $ 50/ton.

The CO2 is stored in liquid form and drained at appropriate locations for sequestration or use.

CARBON CAPTURE AND STORAGE

DAC to Concrete

Three companies Heirloom, CarbonCure and Central Concrete in California have developed a DAC to Concrete process as follows:

1. **$CaCO_3$ (limestone) is heated by a renewable powered electric kiln which separates the CO_2 and CaO powder.**
2. **The CaO is hydrated to form calcium hydroxide, $Ca(OH)_2$, which spread on trays to absorb CO_2 from the air to form calciumcarbonate, $CaCO_3$ again for a cyclical process.**
3. **The CO_2 is mixed with a new water technology to wastewater used to clean concrete trucks.**
4. **The CO_2 enriched water is directly pumped in the concrete trucks where it mineralizes with the concrete for permanent storage.**

Microsoft entered into an offtake agreement on the CO_2. Frontier buyers acquired 26,900 tons at $ 99.

CARBON CAPTURE AND STORAGE

DAC to Baking Soda

A team from Lehigh University and the Georgia Tech Shenzhen Institute have develop a process to capture CO_2 and convert it to baking soda. They use a new type of sorbent made of synthetic raisin that, when dipped in a copper-chloride solution forces the CO_2 in the air to bind with the raisin in a filter. The sorbent can be regenerated using a salt solution. The end result is the production of H_2CO_3 (baking soda), which is a harmless chemical. In fact, the filter can be washed with seawater which produces the baking soda directly. The baking soda does not cause environmental harm and makes the seawater less acidic.

The advantage of the process is that it is three times more efficient than current methods and uses considerably less energy.

CARBON CAPTURE AND STORAGE

Ocean based CO2 removal

The Equatic process of UCLA consist of passing seawater between charged electrodes and based on electrolysis create chemical reactions whereby CO2 dissolved in seawater and CO2 from the air combine with calcium and magnesium ions to produce to produce solid calcium and magnesium carbonate which is stable for at least 10,000 years. In the process also hydrogen is produced.

Equatic has a contract with Boeing to remove 62,000 tons of CO2 per year and produce 2100 tons of hydrogen. The believe that the process can be scaled up to millions of tons by 2028 for less than $ 100 per ton.

Equatic together with Deep Sky are planning a plant in Quebec for the removal of 109,500 tons per year of CO2 and the production of 3,600 tons of green hydrogen per year. Equatic claims costs of $ 100/ton.

CARBON CAPTURE AND USAGE

DAC to SAF

Mission Zero Technologies has produced the first UK DAC plant.

This was purchased by the Translational Energy Research Centre of the University of Sheffield to produce Sustainable Aviation Fuels (SAF).

CARBON CAPTURE AND USAGE

DAC to Sodium Bicarbonate

Tata Chemicals has opened the first carbon capture and usage plant in the UK. It uses CO2 captured from emissions of one of its plants.

It produces *Ekocarb,* a sodium bicarbonate that is used for heamodialysis for kidney treatment and for a wide range of other uses for detergents, animal feed, water purification and pharmaceuticals.

In total the production will be 130,000 tons per year.

CARBON CAPTURE AND USAGE

CO_2 to Methane

McGill University uses copper cluster of nanoscale copper as a catalyst to directly convert CO_2 into methane.

It is a process developed by Mahdi Salehi Ph.D.

It would in principle permit a continuous loop of burning methane producing CO_2 which is than turned back into methane.

No details were given about the chemical formulas.

CARBON CAPTURE AND USAGE

DAC with bacterial CO_2 Conversion

-- The Korea Advanced Institute of Science and Technology is using a bateria *Cupriavidus necator* to pull CO_2 directly from the air and produce a type of polyester: poly-3-hydroxybutyrate.

They used a synthetic membrane to separate the bacteria from the toxic products (for bacteria) that are produced as by product.

The process needs electricity to start and is done in batches.

However, despite the electricity costs the production of polyester is much cheaper.

They note that the process can be easily scaled up.

CARBON CAPTURE AND UTILIZATION
CO_2 CONVERSION

Very much in the research phase is a rather different process. This is CO_2 conversion.

A research team of Lund University (Sweden) is using solar power with advanced materials and ultra-fast laser spectroscopy to convert CO_2 directly into CO, which would be the basis for producing synthetic fuels.

The advanced material is a covalent organic framework (COF) which absorbs solar energy efficiently. By adding a catalytic complex to the COF the conversion to CO happened without requiring additional energy. Many steps are still required to turn this in a large-scale process.

-- The University of Waterloo has developed a cheap process to convert CO_2 into CO based on the electrolysis of CO_2 using water and electricity. The CO in turn can be used to produce ethanol or other substances.

-- New York's Dimensional Energy is converting CO_2 into Sustainable Aviation Fuel and other products and is backed by Microsoft.

CARBON CAPTURE AND UTILIZATION

CO_2 CONVERSION

(continued):

-- The University of Twente, the Netherlands, in collaboration with Shell, has developed a new process to convert CO_2 into CO based new molecules that act as co-catalysts and works with considerably less electricity requirements. The CO in turn can be used to produce ethanol or other substances.

-- The University of Illinois Chicago is converting CO_2 directly into high purity ethylene, based on a novel carbon capture unit and a conversion; half of it filled with a water based solution containing H_2 which reacts with CO_2 supplied through a filter to form ethylene.

-- David Heldebrant of PNNL is extracting CO_2 from flue gasses with a special solvent and subsequently turning it into methanol. They believe carbon capture and conversion can be done for $ 39/ton CO_2.

CARBON CAPTURE AND UTILIZATION

ARTIFICIAL LEAF

-- An European consortium headed by Prof. Galan-Mascaros of the Institute of Chemical Research of Catalonia has come up with an articificial leaf that is 10% efficient in producing fuel from CO2 and H20 using sunlight. They also produced H2 and H2-storage element (formate) which permits continuous production of fuel.

It was done with Cu-S and Ni-Fe-Zn oxide electrodes and a Si-based photovoltaic module.

This is done with low cost and scalable materials.

They are now working on a large scale prototype.

CARBON CAPTURE AND UTILIZATION

METHANATION

-- Mitsubishi Heavy Industries is capturing CO_2 from a waste-to-energy plant.

The CO_2 is transported from the plant to a methanation unit owned by Tokyo Gas. The CO_2 is then used for methanation. The methanation occurs by a reaction with H_2.

The power that is used for the process comes from the waste-to-energy plant and is therefore renewable energy. The end product is e-methane.

Obviously also the hydrogen would have to be green hydrogen for this process to be considered a complete CCU project. No mention was made in the project about this matter.

CARBON CAPTURE AND STORAGE OR USAGE

Possibilities

As will be obvious from the above examples breakthroughs in CCS could dramatically change the path of energy transition by making regular fossil fuels acceptable for power generation or industrial use.

Processes that could simply take CO2 out of the air economically (against carbon prices) anywhere in the world could have a very significant impact.

This could significantly increase the possibility for a successful energy transition.

Currently the largest planned carbon capture project is the 10 mln tons per year project for the Bayu-Undan gas field in East Timor.

MISCONCEPTIONS FUTURE ENERGY

1. **Renewals will replace oil products and gas –**

-- *Mostly not directly, renewals are producing electricity and heat, which in turn is used in light vehicles, steel production and some other sectors. It is the electricity and hydrogen that will compete with oil products and gas.*

2. **Natural gas will always be needed because renewables are intermittent.**

-- *No, gas will not longer be needed if cheaper storage becomes available.*

MISCONCEPTIONS FUTURE ENERGY

3. However, cheaper storage is unlikely because battery costs may go up because of more expensive rare metals.

-- No, utility type storage is not dependent on lithium-ion batteries. Other batteries, such as sodium-ion batteries and flow batteries which do not use rare metals as well as other types of storage, such as gravity storage will start to play a significant role.

4. Creating 100% clean power generation by 2050 to combat climate change will be a huge burden for the world.

-- *Yes, the investments will be gigantic and it therefore that NetZero is unlikely going to be achieved by 2050, but more likely in 2070. However, the investments will be highly beneficial since renewables by 2070 could produce electricity (including storage) for 30% or less than the electricity costs today. After 2070 the world will have limitless, clean and cheap energy.*

MISCONCEPTIONS FUTURE ENERGY

5. Carbon capture and storage could save the petroleum industry.

-- *Traditional CCS will likely remain expensive, but MOFs could significantly lower these costs. COFs might play a role in carbon capture and utilization. Also, biochar methods and direct air capture may start to play a significant role. All of this may maintain a larger role for oil and gas production for energy purposes, while it is likely that by 2070 a significant petroleum industry is necessary to maintain non-energy feedstock production.*

6. Green hydrogen is likely to remain too expensive.

No, with lower energy and electrolyser costs it will soon be rather competitive.

***7.* Creating carbon negative developments is complicated.**

No, some forms of BECCS are easy and very cheap.

CLIMATE CHANGE

Carbon Neutrality

Since the signing of the Paris Agreement in 2015, there has been an increasing trend of countries, governmental entities and companies setting the goal of achieving carbon neutrality.

Carbon neutrality is considered a condition of net zero emissions. This means that whatever climate changing emission occur are being offset by activities such as carbon capture and sequestration, planting trees, removing CO2 directly from the air and other offsetting activities.

Achieving a carbon neutral economy requires many inter-dependent policy actions. However, by setting the goal a framework is created with which progress can be measured and the various methods to achieve the goal can be promoted.

CLIMATE CHANGE

Carbon Neutrality Commitments and Goals of Countries

In general, there is skepticism among analysists as to whether the "lofty" goals can be achieved in the time frame that is being indicated. However, the fact that many governments and companies are now setting COMMITMENTS in law or goals is an important indicator of desire to achieve effective climate change policies. Following are the target dates for goal setting countries:

-- 2014 – Suriname – claims carbon neutrality due to forest cover

-- 2020 – Bhutan – is already carbon neutral, taking into consideration the large forest cover and hydropower.

-- 2030 – Barbados, Uruguay, GUATEMALA,MALDIVES,

-- 2035 – FINLAND,

CLIMATE CHANGE

Carbon Neutrality Commitments and Goals of Countries

(continued:)

-- 2040 – ICELAND, AUSTRIA

-- 2045 – Nepal, GERMANY, SWEDEN, Denmark

-- 2050 – a large number of countries committed to 2050:

North America: **CANADA, United States,**

Central America: **Costa Rica, Panama, Honduras,**

South America: **COLOMBIA, Peru, Argentina, CHILE, Guyana, Ecuador, Uruguay,**

Europe: **UNITED KINGDOM, EUROPEAN UNION, Norway, PORTUGAL, HUNGARY, GREECE, FRANCE, SPAIN, NETHERLANDS,**

Africa: **South Africa, Liberia, Cape Verde, Seychelles, Malawi,**

Middle East: **United Arab Emirates, Oman, Israel**

Eurasia: **Uzbekistan, Kyrgyzstan, Armenia**

CLIMATE CHANGE

Carbon Neutrality Goals of Countries

(continued:)

South Asia: **none**

SE Asia-Pacific: **JAPAN, SOUTH KOREA, Malaysia, Vietnam, Thailand, Singapore, AUSTRALIA, NEW ZEALAND, Papua New Guinea, FIJI,**

-- 2053 – Turkey,

-- 2060 – China, Kazakhstan, Brazil, Saudi Arabia, Kuwait, Russia, Ukraine, NIGERIA, Sri Lanka, Indonesia

-- 2070 - India, Ghana

It can therefore be concluded that the commitment to carbon neutrality is widespread among nations, comprising the vast majority of the current world GDP.

CLIMATE CHANGE

Carbon Neutrality Goals of Countries

It is widely recognized that the goal of carbon neutrality cannot be achieved without massive new production of green hydrogen.

It is therefore that the European Union announced in July 2020 a significant hydrogen expansion strategy as part of the "Green Deal". The plan provides for installing:

-- by 2024: 6 GW of clean hydrogen electrolysers producing up to one million tons of hydrogen per year , and

-- by 2030: 40 GW of clean hydrogen electrolysers producing up to ten million tons of hydrogen per year.

It should be noted that countries that exceed their net-zero goals could become significant renewable energy exporters, such as possibly the UK, Morocco and Chile.

CLIMATE CHANGE

Carbon Neutrality Goals of Countries

Many countries in the world have now done one of the following to achieve net zero:

-- declared they already achieved this goal,

-- made a legal commitment,

-- made a declaration or pledge,

-- described the intention in a policy document, or

--have a proposal or are in discussion on the issue.

However, there are also countries that have not yet set a target, such as Egypt, Mexico and Morocco.

Nevertheless, the IEA estimated that in 2023 the CO2 emissions reached a record high of 37.4 billion tons.

CLIMATE CHANGE

carbon neutral cities

Apart from national governments, also other government entities, such as cities, states and provinces aim to be carbon neutral. There is a Carbon Neutral Cities Alliance ("CNCA"). For instance:

-- 2011 – Sydney, already certified

-- 2025 – Copenhagen

-- 2030 – Glasgow

-- 2035 – Helsinki

-- 2040 – Stockholm

--2050 – Vancouver, Washington (DC)

-- 2050 – Amsterdam (wants to reduce emissions by 95%),

-- 2050 – Amman (Jordan)

CLIMATE CHANGE

Other carbon neutral entities

A large number of companies are also pursuing carbon neutrality.

Following are some examples:

-- 2030 – Google, Microsoft, Apple, Uber, Heathrow Airport, Facebook, General Electric

-- 2030 – Volvo plans all vehicles to be electric

-- 2035 - General Motors plans all vehicles to be electric

-- 2039 – Unilever

-- 2040 - RWE, Walmart, Volvo, FEDEX, Heineken

-- 2045 - SoCalGas

-- 2050 – Duke Energy, FirstEnergy, Maersk Shipping, Delta Airlines, British Airways, ArcelorMittal, ThyssenKrupp, Vale, Ford Motor Co,

CLIMATE CHANGE

Other carbon neutral entities

Amazon reached 100% of renewable use for power in 2023, several years ahead of schedule of the target of 2030.

They invested through PPAs in more than 500 solar and wind projects in 27 countries.

This applies to all of the Amazon operations.

CLIMATE CHANGE

IMF Report

In its recent IMF report "Climate Crossroads: Fiscal Policies in a Warming World", the IMF is concerned that current climate change policies are not sustainable and would lead to very significant additional debt.

The report assesses possible optimal alternatives in terms of cost-effectiveness, political acceptability and other factors.

It concludes that expenditure-based climate policies need to be reduced and replaced by other policy alternatives to be sustainable.

CLIMATE CHANGE

Inability of developing countries to finance climate change

Despite, the positive climate change policies of most countries, it is important to note that the developing countries simply do not have the funds to support large scale climate change investments.

The June 2023 Paris conference to design a "new global financial pact" was a failure. In 2000 the developing world, excluding China, emitted less than 30% of the annual carbon emissions. In 2030 the majority of emissions will be from these developing countries.

According to Hanan Morsy, an UN official, Africa will need $ 2.5 trillion extra by 2030.

This is a very important reason why VME predicts that the achievement of net zero in 2050 is simply not possible. This can be at best achieved by 2070, as will be detailed in the later forecast.

CLIMATE CHANGE

World Bank Report “The Critical Link” 2024

The World Bank Report, entitled “The Critical Link”, 2024, evaluates the financial status of utilities.

The UPBEAT data base evaluates 180 utilities, of which 112 are from Low Income Countries and Lower Middle Income Countries.

Of the utilities of these countries, only 28% receives sufficient revenues to cover their operating and debt service costs, 19% cover the operating costs only, and 53% do not cover these costs.

This amply demonstrates how utilities of LIC and LMIC countries simply to not have the cashflow for any reinvestment, let alone the acceleration required to introduce renewables on a large scale.

Yet at the same time as much as 700 million people have no access to electricity at all.

VME ENERGY FORECAST

Climate Change Effects

The VME forecast that the world will only achieve NetZero by 2070 should be a matter of significant concern.

Recent scientific studies indicate that climate change effects may be more pronounced that previously estimated:

-- A new study of the cores of the ice sheet of Greenland by Paul Bierman of the University of Vermont, indicated that the ice sheet may melt faster than anticipated. Once the total ice sheet melts sea level will rise 7 meters.

-- A new study by Peter Ditlevsen of the University of Copenhagen indicates that the Atlantic Meridional Overturning Circulation has a 95% certainty to stop between 2025 and 2095 with dramatic climate effects.

VME ENERGY FORECAST

Climate Change Effects

(continued):

-- Of major concern is the so-called "Dooms Day Glacier", the Thwaites glacier in Antarctica, which is the size of Florida.

The collapse of the glacier would result in an increase of the sea level of 70 cm.

However, the glacier holds back the surrounding ice and therefore the collapse could ultimately result in a sea level rise of 3 meters.

Scientists have different estimates as to when the collapse could occur which range from the next 5 to 500 years.

VME ENERGY FORECAST

Climate Change CO_2 levels

In this respect it should be noted that the most recent (March 2024) readings on the facility on the Mauna Loa volcano in Hawaii were 426 ppm of CO_2. This was an increase of 4.7 degrees compared to the previous year

This is significantly above the level of 280 ppm before the industrial revolution.

Scientists believe that temperatures will start to exceed 2 degrees Celsius above pre-industrial levels once the CO_2 content reached 450 ppm.

Therefore, at this level the Paris Agreement goals will be exceeded.

VME ENERGY FORECAST

Climate Change Fossil Fuel Use

It should also be noted in accordance with the Statistical Review of the World Energy report fossil fuel use in 2023 reached a maximum of 505 EJ out of a total energy use of 620 EJ.

Also emissions exceeded for the first time 40 Gigatonnes of CO2.

CLIMATE CHANGE

IEA Roadmap

The International Energy Agency (IEA) published *"Net Zero by 2050 – A Roadmap for the Global Energy Sector".* In this Roadmap the IEA illustrates how the world can achieve net zero carbon neutrality by 2050. The scenario is illustrative, not prescriptive.

The Roadmap is based on the assumption that nations will terminate the exploration, appraisal and development of new petroleum deposits and only continue to develop oil and gas fields that have already been approved for development.

Instead, the world would significantly accelerate the development of renewable resources and at the same time strongly increase the efficiency of energy use. The following three tables show the overview.

CLIMATE CHANGE

IEA Roadmap

World Energy Supply (EJ)	2020	2030	2040	2050
Total energy supply	**587**	**547**	**535**	**543**
Renewables	69	167	295	362
Traditional use of biomass	25	-	-	-
Nuclear	29	41	54	61
Unabated natural gas	136	116	44	17
Natural gas with CCUS	1	13	31	43
Oil	173	137	79	42
Unabated coal	154	68	16	3
Coal with CCUS	0	4	16	14

It is remarkable how the energy consumption and supplies actually decline despite the strong growth of the population and the world GDP (PPP). Oil supplies in 2050 would be primarily used for non-energy purposes, such as feedstock for petrochemical industries. The oil price would drop to $ 24/bbl.

CLIMATE CHANGE

IEA Roadmap

World Final Energy Demand (EJ)

	2020	2030	2040	2050
Total final consumption	**412**	**394**	**363**	**344**
Electricity	81	103	140	169
Liquid fuels	158	143	96	66
Gaseous fuels	68	68	60	53
Solid fuels	89	61	46	35
Heat	13	12	9	6
Other	3	7	11	15

About half the final energy consumption will be based on electricity, in part as a result of the full electrification of cars and trucks. A significant share of the gaseous fuels will be hydrogen. Solid fuels will be largely modern solid biomass and only a minor amount of coal.

CLIMATE CHANGE

IEA Roadmap

World Electricity Generation (TWh)	2020	2030	2040	2050
Total generation	**26 778**	**37 316**	**56 553**	**71 164**
Renewables	7 660	22 817	47 521	62 333
Nuclear	2 698	3 777	4 855	5 497
Hydrogen-based	-	875	1 857	1 713
Fossil fuels with CCUS	4	459	1 659	1 332
Unabated fossil fuels	16 382	9 358	632	259

About 88% of the electricity generation will be based on renewables, largely solar and wind. Hydrogen will play an important role both for storage of energy and generation of electricity. Nuclear energy would double.

CLIMATE CHANGE

IEA Roadmap

The IEA Roadmap will result on worldwide basis in enhanced employment by reducing employment in the fossil fuel sectors, but more than compensating these losses with increased high quality employment in renewables.

The Roadmap will have a devastating impact on current oil and gas exporting nations. The Saudi Energy Minister dismissed the report as a sequence from La La Land.

The Van Meurs Energy analysis indicates that the Roadmap would have very serious negative impacts on low income and lower middle-income oil and gas exporting nations, such as Nigeria, with a high risk of creating major social instability as a result of loss of almost all oil and gas government revenues by 2050.

CLIMATE CHANGE

IEA Roadmap

During 2020-2021 examples of countries with petroleum licensing rounds and signing of new contracts are: Norway, the UK, Austria, Australia (Queensland), various states and the federal government of the United States, emirates of the UAE, Russia, China, Timor Leste, Malaysia, Argentina, Brazil, Colombia, Suriname, Uruguay, Syria, Oman, Liberia, Botswana and Zimbabwe. Nigeria has passed the Petroleum Industry Act, and plans a licensing round in 2023. Israel, Angola, Tanzania, Egypt and the UK had licensing rounds in 2023.

It is highly unlikely that these countries are going to follow the advice of IEA to stop promoting exploration and development of petroleum.

CLIMATE CHANGE

Impact on Metals Markets

The climate change developments will have a huge impact on the metals markets due to very significant use of certain metals. The Economist (March 26,2022) did detailed research on this matter. They lists the following countries as the new "Green Giants" in terms of revenues from future metal production:

-- Aluminum: China, Australia, Brazil

-- Cobalt: Congo, Russia, Australia

-- Copper: Chile, Peru, China

-- Lithium: Australia, Chile, China

-- Nickel: Indonesia, Philippines, Russia

-- Silver: Mexico, China, Peru

CLIMATE CHANGE

Impact on Metals Markets

According to *The Economist* the world needs 6.5 billion tons of metals before 2050 to achieve the climate goals.

This is not just lithium, cobalt and nickel, but also steel, copper and aluminum. That output is several times larger that the capacity today.

Significant investment is required. However, miners are reluctant having experience boom and bust before.

It should be noted that investment is impeded by resource nationalism and misguided environmentalism. The recent closure of a copper mine in Panama is a good example. It may take 16 years between discovery and production to create a new mine. Just acquiring the permit could take a decade.

CLIMATE CHANGE

Impact on Metals Markets

There is considerable concern that the shortage of metals will limit the possible growth of renewable production and use of batteries. There will likely be significant effects and may be another reason that the 2050 net zero goals will not be achieved.

However, this PowerPoint presentation also indicates that intense R&D is being carried out to make production of renewables, energy storage, batteries, hydrogen production and other aspects of the energy transition less reliant on these scarce metals.

An interesting example is the development of tetrataenite by the University of Cambridge with the significant potential to replace rare earth for magnets.

CLIMATE CHANGE

Impact on Metals Markets - Recycling

There is considerable R&D being done on battery recycling.

A team of Rice University has developed a method to 98% of metal from various types of mixed battery waste.

They use a Joule heating technique to bring combined cathode and anode waste to 2100 degrees Kelvin, making them soluble in low concentration acid.

The process takes much shorter than traditional methods and uses less chemicals, thereby potentially reducing the cost of recycling considerably.

CLIMATE CHANGE

Impact on Metals Markets – New Discoveries

It is likely that important new discoveries will also be made.

A typical example is the possible McDermitt Caldera deposit on the Nevada-Oregon border.

The deposit may contain as much as 100 megatons of lithium.

CLIMATE CHANGE

Impacts of lack of success will be significant

As almost the entire scientific community is explaining, the impacts of lack of success with respect to climate change will be very severe.

The most recent UN report predicts that based on current policies and pledges made at the COP conferences, the temperature increase will be between 2.5 and 2.9 degrees Celsius over pre-industrial levels by 2100.

This could have catastrophic consequences ranging from runaway melting of ice sheets to the Amazon rainforest drying out.

Sea level increases may be 1 – 2 meters and the mid Atlantic ocean current may come to a halt creating cold conditions in Northern Europe.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Three Revolutions

In the 2020 – 2050 period will be subject to three revolutions and other developments:

Revolution #1 - Strong penetration of low-cost renewable energy for power generation

Revolution # 2 – Low-cost storage will replace natural gas for power generation and the road transport and industrial sector will be based on renewable electricity.

Revolution # 3 – Emergence of green hydrogen as significant energy source for a variety of transport and industrial purposes as well as biofuel development.

In order to permit the three revolutions a deep transformation of the power grid is required.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #1: Penetration of Low-Cost Renewables

It should be noted that many parts of the world that have poor solar conditions have good onshore wind conditions.

For instance, NW Europe, Eastern Canada, Northern Russia, Mongolia, Patagonia, Alaska and the interior states of the United States all have excellent wind conditions.

This means that already in 2020 in most of the world the LCOE of either solar PV or onshore wind will be cheaper than any new fossil fuel plant (based on Lazard USA conditions).

During the 2016-2021 period, solar and wind capacity has been installed at a rate that is three times the capacity increases of all other electricity sources combined (gas turbines, coal, hydro, nuclear, biofuels and geothermal).

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #1: Penetration of Low-Cost Renewables

Based on our earlier estimate of future energy costs, there will be a rapid penetration of solar PV and onshore wind by 2030. In some areas of the world even offshore wind will be less than combined cycle gas production.

The rapid penetration of renewables in Europe resulted in May 2023 in negative electricity prices of - $0.01 per kWh.

This increase in solar PV and onshore wind will accelerate further after 2030. Offshore wind is already economic in NW Europe and many other areas. Due to reducing cost also offshore wind will start to penetrate rapidly after 2030.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #1: Penetration of Low-Cost Renewables

The year 2023 was a banner year for installing renewables.

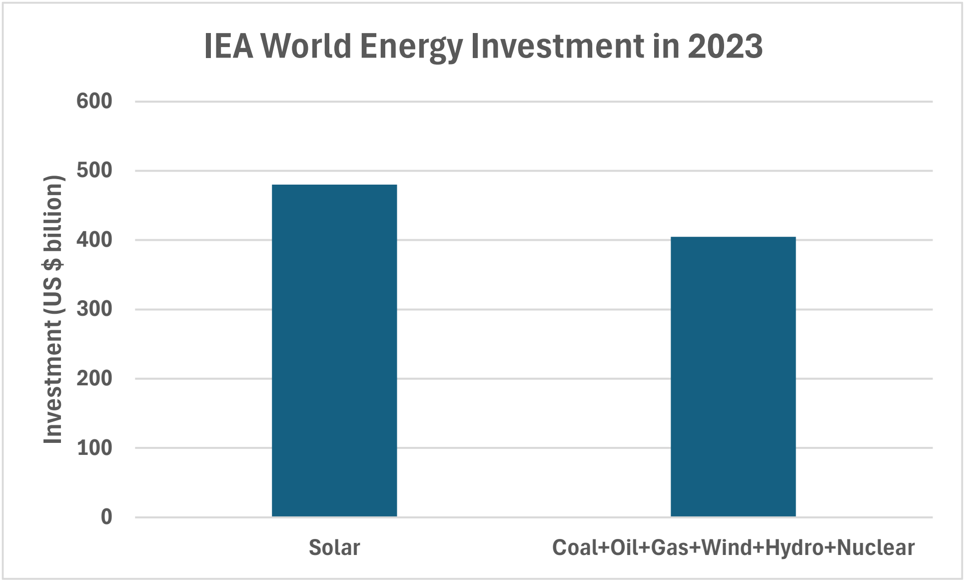
Solar and wind accounted for 80% of the net generation capacity additions. This means four times as much solar and wind capacity was installed as all other (gas, coal, hydro, nuclear, etc.) combined.

Global solar capacity passed 1.4 TW (1,400,000 MW).

The highest renewable capacity per person is in the Netherlands with over 2000 Watt per person installed, compared to a world average of about 300 Watt, based on data of the International Solar Energy Society.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

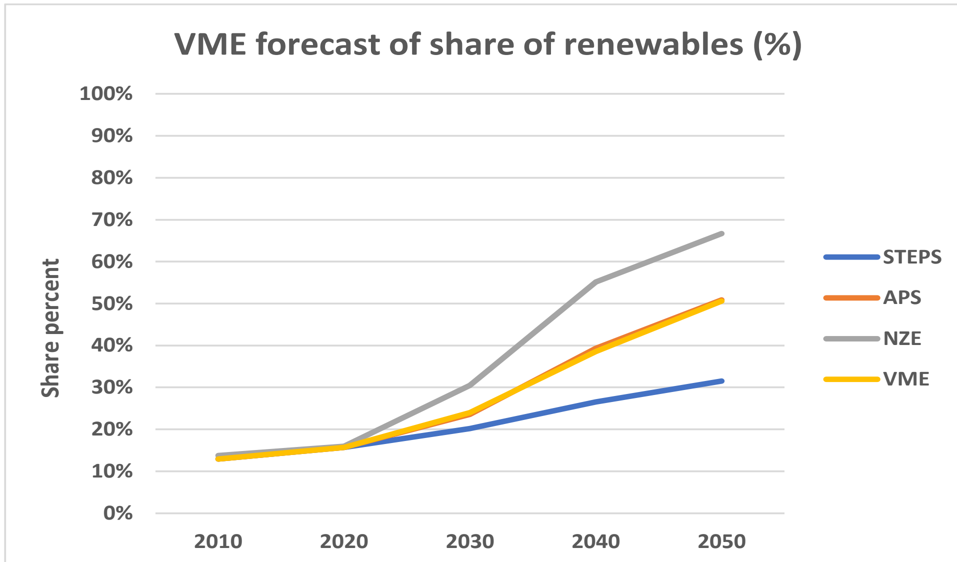
Revolution #1: Penetration of Low-Cost Renewables



The IEA World Energy Investment Report indicates how in 2023 investments for power generation in solar exceed investments of all other energy sources combined (coal, oil, gas, wind, hydro and nuclear).

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #1: Penetration of Low-Cost Renewables



The VME forecast predicts a rapid increase of the share of renewables after 2030 due to the low production costs of renewables at that time. In fact, the share is in line with the APS scenario of 51%. Together with the share for nuclear at 9%, this means that less than 40% of the world energy production will be based on fossil fuels in 2050.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #1: Penetration of Low-Cost Renewables

Since 2019 a considerable number of countries have increased their targets for renewable electricity production by 2030:

-- President Biden wants a target of 80%, however, the EIA believes that a level of 33 – 50% is possible.

-- Europe increased its target from 32% to 40%

-- Japan increased from 18% to 37%

-- India now targets 40% renewables

-- China under the 14th 5-year plan now wants an extra 300 GW of solar and 150 GW of wind

-- Saudi Arabia and the UAE are targeting 50%.

-- The State of South Australia hopes to be 100% by that time.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #1: Penetration of Low-Cost Renewables

As a result of this acceleration of the introduction of renewable energy, it now reasonable to predict that by 2030 about 40% of the world electricity generation will be renewable; or 14000 TWh out of a total of 35000 TWh.

In addition, it is anticipated that nuclear energy will provide between 3200 and 3400 TWh. Also, there may be some small first electricity production based on green hydrogen. So, by 2030 it can be expected that 50% of the electricity will be generated by renewables, nuclear and green hydrogen. Fossil fuels will be providing about 17,500 TWh; the same as in 2019. After 2030 fossil fuels will decline in percentage and absolute terms, as renewable energy can be expected to continue to grow strongly. A decline in coal will be for a while offset by more natural gas.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #1: Penetration of Low-Cost Renewables

An important issue is that still 10% of the world population has no access to electricity, in particular in Africa where in some countries the population without access to electricity exceeds 50%. Off-Grid Solar has the potential to rapidly introduce electricity.

For instance, Lumos in Nigeria, installs a solar panel kit per home that permits a family to enjoy basic electricity, such as for LED lights, laptops, fans and even TV for a few hours. The kit costs $ 13 per month (July 2020 exchange rate for the Naira) and payment can be made from a cell phone.

EIB-ENGIE has a similar program in Uganda.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #1: Interconnections

Of crucial importance for the success of the effective introduction of renewables is the parallel development of long-distance electric cables which can smooth out excesses and shortfalls in renewable energy production, balancing solar, wind and hydropower.

A recent example is North Sea Link, a 1400 MW 720 km high voltage direct current cable between Kvilldal in Norway and Cambois in the UK. This cable became operational October 1, 2021. The estimated cost is 2 billion Euro.

The Copelouzos Group is planning a 3000 MW cable between Egypt and Greece to supply green energy to Europe.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #1: Large volume exports

The fact that renewable energy, such as solar energy, may become very low cost in certain countries, is now stimulating large scale possible exports of renewables.

An interesting possible project is Xlink to connect Morocco and the UK with a large direct current offshore cable to connect to a massive 10.5 GW solar-wind project (with an estimated costs of 1.3 cents/kWh) which is linked to a 5GW/20GWh storage project in Morocco for delivery of 26 TWh per year of firm and flexible of electricity to the UK at a cost of 0.048 pounds/kWh.

Singapore and Indonesia agreed on a 1000 MW link to supply Indonesian renewables to Singapore.

Egypt and Greece agreed to a 3000 MW cable.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 2: Utility scale storage already economic

Other than CSP, at this time utility scale storage is already economic in a number of areas in the world. For instance, the United States has already 40 projects in operation of in total 533MW/1242MWh, mainly in Hawaii, California and Florida jointly with solar PV. A 690 MW project by Quinbrook Instrastructure partners for Nevada just received approval.

Tesla is constructing a 182.5MW/730MWh storage Lithium-ion battery facility in Monterrey, California.

In total the US will add 6200 MW of storage in 2022.

The oil company Total is building a 25 MW/25MWh system in France. InterGen will built the largest storage project in the UK at 320 MW/640GWh. Neoen plans 500 MW/1000 MWh in Australia.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 2: Solar plus Storage Projects

A wide variety of solar plus storage projects are under way:

-- 8minute is preparing the Rexford #1 Solar-plus-Storage project in Tulare Country, California. The project involves 400 MW of solar capacity and 180MW/540Mwh of storage capacity.

-- Hawaii is construction 8 Solar-plus-Storage projects with a total capacity of 300 MW/2000 MWh. The total delivery costs of the individual units varies between 8.9 cents/KWh to 13.0 cents/KWh and the projects are slated for completion in 2022 and 2023.

-- A French bid round for the overseas territories resulted in 47 small projects with a total capacity of 57 MW solar plus storage for an average costs of 11.93 cents/kWh.

-- The Lazard 2020 estimate for solar+storage is 8.1 – 14 cents/kWh

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 2: Wind plus Solar plus Storage Projects

The most comprehensive 24/7 renewable projects are integrated wind plus solar plus storage projects.

One of the largest projects currently being constructed is the Skeleton Creek project in Oklahoma built by NextEra for electricity deliveries to WFEC based on a PPA.

The project involves 250 MW of onshore wind, 250 MW of solar and 200 MW of 4-hour storage.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 2: Projected increases in Storage

Bloomberg NEF estimates that world installed battery storage will increase from about 15 GW in 2020 to as much as 350 GW by 2030, with most of the installations in the US, China and Europe and about 25% of this storage being residential and light industrial.

An important driver for storage is solar plus storage. In particular in the United States due to the continuation of the investment tax credit. It is expected that 3,800 MW will be solar plus storage.

NREL estimates that total storage capacity (including pumped hydro) in the United States will increase from 20 GW in 2020 to 200 GW by 2050. Most of the increases will be 4-hour and 6-hour storage.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Reduction of natural gas for power generation

As indicated earlier, it can be forecasted that the LCOS of utility scale storage by 2030 will be in the 12 – 24 cents/kWh range, based on Lithium-Ion batteries, fully competitive with natural gas based peaking after sunset in most of the world (although DoE targets 5 cents/kWh)

After that, the LCOS is anticipated to drop gradually and the role of natural gas in the energy mix to produce electricity will gradually erode. The VME forecast is that natural gas production will peak in 2030, as presented earlier.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Reduction of natural gas for power generation

As an example of this trend, Wood Mackenzie estimates that the use of utility scale battery storage in the five main European countries will increase from 3 GW to 26 GW by 2030.

The capacity of three other flexible assets, pumped storage, cross border interconnection and gas peaking power, will increase from 122 GW to 205 GW.

After that WoodMac expects that gas peaking power will not contribute further due to the lower costs of batteries.

By 2040 the estimate for battery storage is 89 GW and that of the other three assets 265 GW.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Reduction of natural gas for use in buildings

The important result of Revolution # 2 is that increasingly ever cheaper renewable electricity will be produced capable of supplying the economy 24 hours per day.

This has other effects on natural gas. In 2030, 20% of the natural gas will be used in homes and buildings, for heating and cooling and water heating.

Cheap electricity will increasingly be used for electric heat pumps for heating and cooling and for water heating. The details will depend very much on climate conditions and building quality, in particular insulation. According to WoodMac, Europe will achieve 45 million heat pumps by 2030 and during the 2030's 5 million per year will be installed in the residential sector.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Reduction of Natural Gas – The Netherlands

An interesting example could be the Netherlands, which since the gigantic Groningen gas field discovery has relied for much of its economy on natural gas. The goal is to be carbon neutral by 2050. Therefore, a study by was done by Shell and GasUnie to see how natural gas could be replaced economically for buildings. The study resulted in the following conclusions: 10% would be difficult to replace, 40% could be reduced by better insulation, 15% could be replaced by electric heat pumps, 15% by hybrid heat pumps (relying in part on gas), 14% by district heating based on waste heat and 6% by district heating based on geothermal heat. Where natural gas could not be replaced, it was contemplated that green hydrogen would be used based on wind energy (which Shell and GasUnie plan to produce).

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Reduction of Natural Gas

The reduction of natural gas became rather strong during the first half of 2023.

Reuters based on the Global Energy Monitor reported that in the first half of 2023 in total 68 gas power plants were put on hold or cancelled.

Battery operators are already supplying back-up power to grids competitive with natural gas.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Electric Vehicles

Another well known result of the expected low-cost batteries by 2025 is that Electric Vehicle ("EV") sales will continue to grow rapidly.

By 2040 Bloomberg BNEF expects 57% of the passenger vehicle sales to be EV's, which at that time would represent 30% of the passenger vehicle market of 1.68 billion vehicles. BNEF also expects 56% of the light commercial and 31% of the medium commercial vehicle sales to be electric. In total 70% of the busses in operation will be electric.

In 2022 already 13% of light duty vehicles are EVs. Apart from Tesla, almost all other car manufacturers are now considering or already selling EV's. This will severely impact on gasoline demand.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Electric Vehicles

The report "Global EV Outlook 2024" published by the IEA mentions several important issues.

They report that it is estimated that in 2024 the world EV sales will top 17 million, which means 20% of the car sales will be EVs.

In 2024 the market share of EVs could reach 45% in China, 25% in Europe and 11% in the United States. EVs also start to penetrate in some developing markets, such as Vietnam and Thailand.

Based on the IEA Announced Pledges scenario, two-thirds of all vehicles sold in 2035 could be electric, reducing oil consumption by 12 million barrels per day.

Much of the future growth depends on cost reduction of the cheaper car models.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Electric Vehicles

The 2021 World Energy Outlook report provides in its Table 4.3 an overview of automakers that intend to go 100% EV for passenger cars by certain dates. For instance:

2025 -- Jaguar

2027 -- Alfa Romeo

2030 -- Ford (in Europe), Bentley, Fiat, Volvo

2033 -- Audi

2035 -- Volkswagen (in Europe), General Motors, Hyundai

2040 -- Honda

Also, the EU agreed that there will be no longer fossil fuel vehicles after 2035

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Electric Vehicles

-- Honda anticipates that it can reduce fuel cell costs in half by 2030 for its fuel cell electric vehicles (FCEVs), based on the CR-V 5-seater SUV. They will also sell the fuel cells in the open market in cooperation with General Motors.

-- Nissan anticipates to reduce its EV costs by 30% by 2026 compared to 2019 levels. They also like to reduce the use of rare materials. Currently the Nissan Leaf uses rare materials for 25% of its weight. Nissan hopes to reduce this to 1%.

-- Toyota is preparing an EV battery that will be half the size, weight and costs by 2027 based on solid-state technology. These batteries can also produce cars with a range of 1200 km that can be charged in 10 minutes.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Electric Vehicles

It should be mentioned that the Chinese company BYD has already achieved the above objective set by the IEA of delivering low-cost EVs.

Following are now available:

- **The Qin Plus EV and PHEV at a price of $ 15,200. The car has a range of 420 km.**
- **The Dolphin EV Honor at $ 13,900.**
- **The Seagull EV at $ 9,700.**

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Electric Vehicles - Range

Not only will EVs become cheaper, also many companies are now working on an extended range.

EVs with a range of more than 1000 km (621 miles) are now:

-- existing: the Zeekr with a Qilin battery in China

-- contemplated:

Mercedes-Benz Vision EQXX

Toyota

Michigan Start Up – Our Next Energy

It can be expected that by 2026 or 2027 many of the car companies will offer models with such a range.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Electric Vehicles - Government

The Canadian Federal Government has decided that from 2035 onwards all vehicles sold in Canada must be zero-emission vehicles.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: ONE's batteries

A much longer range could also be achieved with a new type of battery being developed by a Michigan start-up Our Next Energy (ONE).

Its dual chemistry battery achieved 978 km with a BMW iX.

The battery is capable of 450 Wh/L energy density.

They combine a lithium iron phosphate battery with high energy density range extender which feeds the battery.

They reduced lithium by 20%, nickel by 75% and use minimal cobalt.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Nyobolt batteries

A remarkable achievement is also the Nyobolt battery.

This is a battery that can be charged from 10% to 80% in under 5 minutes.

Nyobolt is a Cambridge based company.

The battery still charges to 80% even after 4000 charges and discharges.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Sodium batteries

The Chinese companies BYD and Huaihai have signed a deal to built a 30 GWh sodium battery plant for microcars in Xuzhou.

The sodium-ion battery market is maturing.

However, due to the significant recent drop in lithium prices, the economic advantage of sodium-ion is less than it was anticipated before.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: New Solid State Lithium batteries

The Harvard John A. Paulson School of Engineering and Applied Sciences has developed a new lithium metal solid-state battery that performed already 6000 charges and discharges and can be charged in minutes.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Electric Vehicles – Charging Points

A major problem with Electric Vehicles today is the lack of charging stations.

However, some interesting developments could change this.

Walmart is planning to install thousands of charging stations at their stores by 2030.

7-Eleven has announced is 7Charge program of installing fast DC chargers at its outlets in the USA and Canada.

ENEL plans to install 2 million EV chargers in the US by 2030.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Solar Vehicles

--Aptera Motors in California will soon introduce a solar powered three-wheeler that will drive primarily on solar generated in the roof. The solar generation (depending on climate) will permit the car to go for 40 miles per day without charging. It has a 100-kWh battery pack for the occasional electricity supply provided through connecting to the regular grid. The 250-mile range model is priced at a relatively low $ 25,900.

-- Lightyear in the Netherlands is working on a full-scale solar electric car with a low-cost model to be available early 2025.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Integrating PV in EVs

-- Kenaka solar panels of 180 cm2 and 26.6% efficiency will be installed on the Toyota Prius EV staring in 2023 for partial solar supply.

A study done by European Universities under Miguel Centeno Brito indicates that adding solar panels to cars could add from 11 to 29 km per EV per day in urban areas, cutting charging needs in half.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Electric Airplanes

Air transport will see introduction of electricity, but not on a significant scale.

Harbour Air, a Canadian company flying planes (short distances) between Vancouver Island and mainland British Colombia is converting their fleet to electric planes.

Avinor, the Norwegian company running airports, plans to order electric planes for short haul flights.

Air Canada has entered into a contract with Heart Aerospace to purchase 30 electric airplanes with a capacity for 30 passengers aimed at short haul flights to enter into service in 2028.

RECENT has developed an electric Seaglider with a range of 300 km at a speed of 300 km/hour.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Electric Air Taxis

--Vertical Aerospace, Bristol, UK, has pre-orders for 1000 aircrafts from American Airlines, Virgin Atlantic and others for its air taxi, VA-X4.

This is a 4 person aircraft plus pilot that can take off vertically like a helicopter but flies like a plane at 200 miles per hour over a maximum distance of 100 miles. It is totally electric and carbon free. It is planned as a commuter aircraft to/from airports, such as Heathrow.

--Similarly, Joby Aviation also hopes to start electric air taxis in the near future with electric air taxis with a range of 150 miles with four passengers.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Air taxis and air freight

-- A Dutch startup called Electron Aerospace is developing the Electron 5 aircraft.

It would seat in addition to the pilot four passengers. It is intended to have a range of 500 km (plus a safety reserve for another 250 km) at a speed of 350 km/h. Is has pre-orders of $ 250 million.

-- Embraer has flown its first E190F a freighter which is a converted passenger jet. It has a payload of 13,500 kg. It is claimed to be 30% more cost effective than a narrow body.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: eVTOLS

Archer Aviation has begun construction of an eVTOL plant in Georgia intended to produce 650 electric aircraft per year, with a possibility to expand the facility to 2,300 aircraft per year.

The plant will be built in partnership with Stellantis.

The eVTOL has a range of 60 miles and a speed of 241 km/hour.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Electric HyperBikes

In the Netherlands already half the number of new bikes is electric bikes. Electricity supports the velocity of the bikes. The speed can be increased from normally 25 km/hour, based on pedal power to 45 km/hour based on electric supported pedal power.

The company VanMoof is now introducing (by 2022) the stronger and faster VanMoof V bike which can go 50 km/hour. The bike has electric support on the front and back wheel, has a stronger frame and wider tires. The costs is 3500 Euro. It is introduced as the ideal bike for home-to-work transport, thereby replacing cars. It is estimated to have an impact on the reduction of car use and thereby CO2 emissions

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Electric Vessels

Bangkok will have electric ferries on the river.

Ellen, an electric-powered ferry is already operating in Denmark carrying up to 200 passengers and 30 cars between islands.

A Swiss company Candela has developed a luxury water taxi called P-8 Voyager, with zero noise, zero wake and zero carbon emissions. Candela P-12 will become a regular shuttle in Stockholm.

Yara International will soon commence its electric containership which is 80 meters long and is operating without crew.

Incat Tasmania is building the largest electric ferry of 130 meter long with a capacity of 2100 passengers and crew and 225 cars, based on a battery pack of 40 MWh.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Electric Cargo Drones

A german company will deliver 12,000 of its Wingcopter 198 electric drones for cargo delivery across Africa.

It cruises at 144 km/h over a range of 110 km and can carry 6 kg of cargo with three possible drop offs.

It will operate in 49 sub-Saharan countries.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Electric Trains on Wind Energy

The Dutch railways now operate on 100% wind energy based on a contract with the electricity company Eneco.

The railway system features 5,500 train trips per day and 600,000 daily commuters.

A single windmill operating for an hour can power a train for 120 miles.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Solar for Cement Production

Synhelion and Cemex are investing in a pilot cement plant based on solar thermal energy. The process will produce clinker, the most energy intensive part of the process. The process uses solar heat directly.

Synhelion's process delivers high temperature heat beyond 1500 degrees Celsius.

Also, the process makes it much easier to capture CO2.

The process will completely replace fossil fuels for cement production.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Renewables for Cement Production

Sublime Systems received the ASTM C1157 designation, which permits Sublime to produce its fully useable cement entirely from renewable resources.

Sublime Systems is using an electrochemical process that is bypassing kilns altogether and can be based on renewable electricity.

Cement results in 8% of the world CO2 emissions, so this could be a very important change.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Carbon Neutral Cement Plant

An alternative to using renewables is to produce cement in a different way.

Thyssenkrupp Decarbon Technologies has started the construction of a cement plant in Schleswig-Holstein in Germany which will be based on pure oxygen injection in order to create flue gasses that will be mostly pure CO2, which can in turn be easily recovered and stored or sold as a chemical.

The plant will be operational in 2028 and is estimated to capture around 1.2 million tons of CO2 per year.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Renewables for Iron Production

Electra, a clean iron company, will start a pilot plant in Boulder, Colorado to make clean iron at only 140 degrees Fahrenheit entirely based on renewable energy.

The process consists of removing from iron ore or steel scrap the impurities to produce 99% pure iron.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Renewables for Other Industries

Heineken has announced that it will commission a 30 MW CSP plant in Spain with 68 MWh of storage in Spain at a cost of $ 22 million for the production of beer.

The Morocco based OCP Group will invest $ 360 million to power its phosphate mines with 400 MW of solar power and 100 MWh of storage.

The Chilean copper mine Codelco has awarded 1.8 TWh renewables per year to a number of companies under 15 years PPAs, ensuring that 85% of its electricity is generated by renewables by 2026.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #2: Solar for Cement, Ceramics, Glass and Steel

Researchers of ETH in Zurich have achieved temperatures of 1050 degrees Celsius based on solar.

The starting point is a concentrated solar installation which with mirrors concentrates the solar heat on a focal point.

However, there are limitations with this concept.

The researchers developed a thermal trapping device which further enhanced the heat to reach these high temperatures.

This makes it in principle possible to create high temperature heat for cement, ceramics, glass and steel.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Hydrogen for Oil Refining and Ammonia

Assuming an ever-lower cost per kg towards 2050, hydrogen will increasingly penetrate the market. To begin with green hydrogen will increasingly replace hydrogen produced from fossil fuels for the purpose of refining and ammonia production and other industrial processes, once costs start to fall below the $ 2/kg range.

Currently about 6% of the natural gas production is used for these purposes. The ammonia production is expected to expand significantly, while use for oil refining is limited based on the limited need for merchant hydrogen due to the fact that refineries produce hydrogen as part of their integrated processes.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Hydrogen Revolution -TMR

Although VME expects green hydrogen to play only a major role after 2030 when costs have declined sufficiently, other consulting firms expect a much faster growth already during the 2020-2030 period. As mentioned earlier in this presentation under "Hydrogen", at very high gas prices of 2022, green hydrogen is cheaper to produce than grey hydrogen.

TMR, an India/US firm expects the hydrogen market to grow at a spectacular rate between 2022 and 2031 of 51.6%. This is consistent with an Guidehouse Insights estimate of the growth of electrolyzers of 8000% during this decade.

The main source of electricity for the hydrogen is anticipated to be solar and PEM the main type of electrolyzer.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for Ammonia

BloombergNEF expects green ammonia to expand to 32 million tons by 2030. Four recent projects:

-- in Spain, Iberdrola and Fertiberia will invest in a plant which will produce 0.2 million tons ammonia per year based on 100 MW solar, 20 MWh storage and 20 MW electrolysis.

-- in Saudi Arabia, ACWA, Air Products and NEOM will make a $ 5 billion investment in a plant that will produce 650 tons of hydrogen/day as well as 1.2 million tons/year of green ammonia, based on solar and wind energy.

-- The CIP group in Denmark will built a 1 GW green ammonia plant based on offshore wind in Esbjerg.

-- GH2 will produce ammonia based on wind in Newfoundland

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen as Energy Storage

Hydrogen is increasingly seen as a fuel that can provide large utility scale storage.

Infinite Blue Energy is planning a 1000 MW complex for New South Wales consisting of wind, solar and hydrogen fuel cell generation. Excess wind and solar energy will be converted in green hydrogen which will be used when required.

Germany is planning by 2030 to have 5000 MW of electrolyser capacity in place, in part to supply green hydrogen-based power generation.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for load balancing

Three large project are underway in the United States to use hydrogen for load balancing in New York, Virginia and Ohio, ranging for 600 MW to 1084MW. They are based on the Mitsubishi Hydaptive and Hystore packages. The process is as follows:

-- electrolysis plants convert excess renewable energy to hydrogen,

-- hydrogen is stored in salt caverns or above ground storage facilities, for hours or even seasons,

-- finally, a hydrogen enabled single cycle of combined cycle gas turbine power plant converts the hydrogen in electricity when required.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for load balancing

Another interesting project is in a remote part of NW French Guiana.

The project consists of a 16 MW electrolyser, a 3 MW of fuel cell, 55 MW of solar panels and 20 MW/38MWh storage.

The objective is to deliver 10 MW baseload renewable power from 8 am to 8 pm and 3 MW of baseload from 8 pm to 8 am.

It is a $ 197 million project based on a 25-year capacity contract with EDF.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for Vehicles

Depending on the competitive framework with electric vehicles and vehicles based on the internal combustion engine, green hydrogen may penetrate a larger share of the road transport market. Gasoline in an internal combustion engine has an efficiency of about 20% and hydrogen about 25%. However, a hydrogen fuel cell has an efficiency of 60%.

Hydrogen is anticipated to have a significant impact on long distance freight trucks and heavy transport vehicles. Also, vehicles used for many hours per day, such as buses and taxis are good candidates for the conversion to hydrogen.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for Vehicles

Hydrogen will also become the preferred fuel for transport vehicles requiring significant capacity and capabilities.

-- An interesting example is the new 510-ton dump truck to be used for the mining industry developed by Anglo American. This is a truck with a weight of 220 tons and a possible load of 290 tons. It is entirely fueled by hydrogen. The truck is being tested in the Mogalakwena mine in South Africa.

-- Pure Hydrogen in Australia has the first hydrogen fuel cell mover truck for sale. The truck is called “Taurus” and could revolutionize long haul transport.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for Vehicles with methanol

An interesting option that is being applied in Dailan, China by SINOPEC, is to use methanol as the main product for transport and storage of hydrogen and at the hydrogen distribution stations convert methanol back to hydrogen. It is a simple reaction:

$CH_3OH + H_2O > 3H_2 + CO_2$

It can be carried out at room temperature or slightly higher temperatures. The hydrogen service station can produce 1000 kg of hydrogen per day with a purity of 99.999%. The whole H_2 production facility only occupies 64 m^2.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for Marine Transport

Green Hydrogen could have a significant impact on marine transportation due to the fact that fuel cell technology can be integrated in large ships.

In fact, Switch Maritime in California is building the first 70 foot hydrogen fuel cell ferry for the Bay area.

It should be noted that also ammonia could be used for marine transport.

The Swedish company PowerCell will provide the Norwegian SEAM with two large hydrogen-based ferries capable for 599 passengers, 120 cars and 12 trucks.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for Marine Transport

The Japanese Government, through ClassNK, has granted approval for the first multi-purpose hydrogen vessel for Mitsui Osk Lines (MOL). MOL stated that this is the first low-speed multi-stroke hydrogen fueled engine.

A two year demonstration operation is planned for 2027.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for Rail Transport

Hydrogen trains are already used in Bremerhaven in Germany and are targeted to replace current diesel powered trains in Italy and the UK.

Canada will introduce a hydrogen train in Quebec on a 90- minute tourist route.

Caltrans will start the first inter-city hydrogen train in California.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for Airplanes

Various developments are underway to use hydrogen for airplanes.

Airbus is doing extensive research in hydrogen planes under project ZEROe evaluating three concept hydrogen planes and believes that they may be commercial by 2030.

In the US, Universal Hydrogen and Connect Airlines are partnering to have the first hydrogen planes operational by 2025.

American Airlines and Zeroavia (UK) have signed an agreement that may involve 100 hydrogen-based aircraft engines.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for Airplanes

ZeroAvia is joining forces with Shell to equip the Rotterdam airport for full scale hydrogen airplane transportation.

They hope to have demonstration flights to European airports by 2024 and full-scale commercial operations by 2025.

It will involve all on-the-ground infrastructure. Flights to other airports within a range of 250 nautical miles from Rotterdam are contemplated.

ZeroAvia completed its demonstration flight with a 19-seat Dornier 228 aircraft with a ZA600 hydrogen-electric propulsion system.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for Airplanes

California-based has successfully carried out a maiden flight of a 40-passenger plane based on hydrogen fuel cell propulsion.

The ATR 72 regional aircraft is expected to enter into service. The order book is already 247 aircraft.

The UK Aerospace Technology Institute is designing a 279-seater aircraft, called FlyZero, that can fly halfway around the world; in other words, similar performance as current mid-size aircrafts. It would be equipped with two cryogenic liquid hydrogen tanks at minus 250 degrees Celsius in the back of the plane and two "cheek" tanks in the front of the plane to keep balance.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for Airplanes

Interestingly Japan sees hydrogen airplanes as a way for Japan to get into the plane construction business.

The Ministry of Economy, Trade and Industry has announced a very large $ 33 billion support program to develop this new industry over the next decade.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for Industries

Green Hydrogen could have a very significant impact on the petrochemical industries. If hydrogen can be produced for $ 1/kg or less, it may will also be possible to make synthetic fuels for the petrochemical industries from hydrogen.

Another important possible application is hydrogen for direct reduction of iron ore in the iron and steel industry. Tenova and HBID are in China constructing such a plant for 2021 whereby coal will be replaced with a natural gas mixture with 70% hydrogen.

It is estimated that if green hydrogen can be produced for $ 1.80 per kg in 2030, the costs of green steel will only be 10% higher than conventional steel and costs will become equal or less at lower hydrogen costs.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for Industries

Iris Ceramica and SNAM will develop the first ceramics plant based on hydrogen.

The project will start with 2.5 MW solar and an electrolyser to produce green hydrogen on site. Initially green hydrogen will be mixed with natural gas. Over time the plant may run on 100% hydrogen.

It might also be possible to produce cement with fuels in which hydrogen is an important component. Hydrogen by itself may not be suitable for cement production.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for Steel

In addition to the hydrogen for steel projects mentioned in the previous slides and interesting project is HYBRIT project in Sweden based on direct reduction of iron ore.

In this process iron ore is chemically reduced to sponge iron using hydrogen, which is then smelted into steel with electric arc furnace. It is planning to construct a full size plant in Gallivare.

H2 Green Steel is planning a 5 million tons fossil-free steel plant in Sweden to the operational in 2030.

CAP, Chile's largest steel producter, is constructing a test green hydrogen plant to produce 1550 tons of green hydrogen and 25,000 tons of sponge iron per year.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for Methanol

Liquid Wind is planning to produce methanol from hydrogen created by wind energy and electrolysis in Sweden.

The hydrogen will be combined with the CO2 recovered from the electricity plant of övik Energi. This plant produces electricity and steam for district heating based for 99% on biofuel.

The methanol will be used for marine transport in vessels designed for the use of methanol.

This is therefore methanol produced entirely on the basis of renewable resources. The plant will produce 50,000 tons of methanol per year.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #3:Green Hydrogen for Pure Synthetic Jet Fuel

Potentially a very significant impact of low-cost green hydrogen would be the production of synthetic jet fuel, whereby jet fuel is produced with green hydrogen and pulling CO2 from the air.

The process was already used by Germany in World War II.

Currently the Klesch Group, operating the Heide oil refinery in Northern Germany, is perfecting this process based on hydrogen from local wind farms. Lufthansa committed to use this synthetic fuel for 5% in their jet fuel consumption within 5 years.

However, overall costs are not known and are expected still to be too high for general application.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #3:Green Hydrogen for Pure Synthetic Jet Fuel

Vattenfall and St1 are working towards electro-aviation fuel based on wind energy.

They hope to start in 2029 and work towards one million cubic meters per year, using fossil-free hydrogen. This is sufficient fuel for Arlanda airport of Stockholm.

ETH Zurich has developed a single tower process using concentrated sunlight to very high temperatures, then water and pure CO2 are fed into a ceria-based redox reactor which produces simultaneously hydrogen and carbon-monoxide, or syngas, which can be subsequently used to produce jet fuel and other fuels. The benefit of the process is its simplicity in producing syngas. The project is still in the research stage.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution #3:Green Hydrogen for Synthetic Gasoline

Porsche with a company called High Innovative Fuels has successfully started the production of synthetic gasoline based on green hydrogen based on wind energy and CO2 captured directly from the atmosphere, in the Hari Oni plant in Punta Arenas in Chile.

The plant first produced eMethanol which is converted into synthetic gasoline. The use of eFuels with offer owners of ICE cars the option to become carbon neutral.

The plant will start up at 0.13 million liters per year, and is intended to scale up to 55 million liters per year by the middle of the decade and up to 550 million liters per year before 2030.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen replacing Natural Gas

An important characteristic of hydrogen is that it can be distributed in the regular natural gas pipelines.

For instance, Australia Gas Networks (AGN) is participating in the Hydrogen Park South Australia demonstration project, that will distribute 5% hydrogen in its natural gas distribution system.

The optimal hydrogen content that does not need changes to the gas distribution net work is 20% hydrogen. A Keele University project is carrying out such a trial distribution system based on their own container size hydrogen plant.

With adjustments to boilers and other instruments hydrogen can be transported on a 100% basis through existing gas distribution networks.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen replacing Natural Gas

In Quebec, Canada two companies, Evolugen and Gazifere (an Enbridge subsidiary) have teamed up to deliver green hydrogen to the gas distribution system.

Evolugen will built a 20 MW plant to produce hydrogen on the basis of its hydropower facilities. Approximately 425,000 GJ of green hydrogen capacity will be produced for injection in Enbridge's gas distribution network.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen replacing Natural Gas
Limited Benefits

Based on an IRENA report, adding up to 20% (by volume) hydrogen to natural gas has only limited benefits since it only adds 7% to the energy content. In other words, it reduces emission only by 7%.

Also, the cost of the gas would go up significantly.

Agora Energiewende estimated in 2021 that the replacement by 20% hydrogen would increase the cost of the gas by 33%, largely due to the fact that hydrogen is still expensive to produce.

So, only under scenarios where gas is rather expensive to begin with, could there be some benefit.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for heating homes

Hydrogen is occasionally mentioned as a source for heating homes.

However, it is six times more efficient to heat homes based on heat pumps based on electricity, which in turn would be based on solar and wind.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for Power Generation

Green Hydrogen will be increasingly used directly for power generation.

Companies are designing gas turbines that can operate of the basis of natural gas and can be easily modified to operate on hydrogen. For instance, Rolls-Royce has recently announced the MTU Series 500 hydrogen ready gas engines, with capacities in the range of 250 to 550 kW and 42.6% efficiency.

The size of fuel cells is becoming large enough to generate large scale electricity based on fuel cells. One of the largest power plants based on phosphoric acid fuel cells has been constructed by Hanwha Energy, which is a 50 MW plant based on 100% recycled hydrogen from petrochemical manufacturing.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for Power Generation

A European consortium has run the first gas turbine entirely on hydrogen. The consortium included Engie, Siemens Energy and the UK Centrax.

The advantage is that existing gas turbines using fossil fuels can be converted to hydrogen with a simple process.

Hitachi Energy has developed a Hydrogen Power Generator designed for construction and similar sites and emergency backup for hospitals and hotels. It produces 400 – 600 kVA of power entirely from hydrogen.

It is also already operating a 20 MW plant in Sweden.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Green Hydrogen for Power Generation

Essar Energy Transition will build the first hydrogen-ready combined heat and power plant.

The plant will be built at its Stanlow Refinery.

The plan is to replace the current steam engines and create 125 MW of power and 6000 tons per day of steam, with the plasn to be in operation by 2027.

This will remove annually 740,000 tons of CO2.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Revolution # 3: Ammonia for Power Generation

Another option is to use ammonia for power generation.

Mitsubishi Power is developing the H-25 turbine that can operate on 100% ammonia.

The first power plants operating on ammonia are contemplated for Jurong Island in Singapore and by 2025 for Indonesia.

The advantage of ammonia is that it can be shipped easily and cheaply and that it can be based on green hydrogen.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Other developments: Sustainable Aviation Fuels

Other developments will also impact on the petroleum industry. Many analysts estimate that the main possibility for transforming aviation is the development of Sustainable Aviation Fuels ("SAF").

Since it is estimated that 10 billion passengers will be flying each year in 2050, this energy transition is of great importance.

Abu Dhabi Etihad Airways is working with Khalifa University, Boeing, jet engine maker SAFRAN on producing biofuel from salt-tolerant plants that can be grown in seawater.

At this time biofuels are still not widely used due to the high cost of these type of fuels at the moment.

NREL, MIT and Washington State University have developed a process whereby lignin can be deoxidized to produce aviation fuels.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Other developments: Sustainable Aviation Fuels

There are significant challenges with SAF. If all the aviation fuels required in 2050 would be based on SAF, the amount of cropland to grow crops to be turned into fuel would be 3 million square km of the 18.7 million square km of crop lands.

Obviously, one cannot affect world food production, so ways have to be found to grow the sources of biofuel on non-agricultural lands as discussed under biofuels.

Another problem is costs. The cheapest SAF based on waste oil costs between \$ 0.78 and \$ 2.29 per liter. Synthetic fuels range from \$ 1.30 to \$ 4.70 per liter.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Other developments: Sustainable Aviation Fuels

The European Union nevertheless has adopted the ReFuelEU Aviation Proposal. The rule requires that aviation fuel suppliers gradually increase the percentage of SAF from 2% in 2025 to 70% in 2050.

The mandate covers biofuel, recycled carbon fuels, synthetic aviation fuels. There is also a requirement to gradually increase the share of environmentally attractive synthetic aviation fuel.

The ruling seeks to achieve that CO2 emissions are reduced by two-thirds compared to a “no action” scenario.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Other developments: Green Ammonia as Fuel

Green ammonia could in principle be used directly as fuel. The main issue is nitrogen oxide emissions, which is also a greenhouse gas. However, technologies are being researched to deal with this problem.

Mitsubishi Power is developing a 40 MW gas turbine based on ammonia.

An Australian start-up Aviation H2 intends to use ammonia to fuel jet planes. Ammonia is lighter than jet fuel and has a higher energy density than liquid hydrogen.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Other developments: Steel, Aluminum, Cement

The production of cement, steel and aluminum requires huge amounts of energy. Steel contributes 7% and cement 8% of world CO2 emissions. Being able to produce these three products without emitting CO2 would be a major breakthrough.

In Sweden the HYBRIT (Hydrogen Breakthrough Ironmaking Technology) process is being developed by a consortium of companies (LKAB, SSAB and Vattenfall) and the Swedish Government. The production of one ton of steel results today n 1.8 tons of CO2. This will be reduced to 25 kg. The process uses green hydrogen to be produced with electrolysis based on renewables. To produce all Swedish steel this way 15 Terawatt-hours of electricity would be required. It is expected that the process will be competitive with traditional methods over time.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Other developments: Steel, Aluminum, Cement

ELYSIS, a Quebec joint venture of Alcoa and Rio Tinto is in the process of producing aluminum entirely without any CO2 emissions. They hope to have a commercial pilot plant operational by 2023. The process produces oxygen as by-product. If all of Canada would use this process it would eliminate 7 million tons of CO2 emissions per year.

A wide variety of rather innovative methods is being researched to produce cement without emitting CO2. Some processes use bacteria. Norcem, a Norwegian cement producer hopes to become the first zero-emission plant by using waste products as fuel and eliminating the CO2 by carbon capture and storage. Over time this may become economic.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Adjustments to the Power Grid

The three revolutions discussed above will require a massive transformation and expansion of the power grid.

The *Economist* describes in their *Technology Quarterly (April 5, 2023),* this process in detail.

An interesting example of the scale of the problem is provided by Amprion, a German systems operator. On a sunny windy day at 11 am on a day in July 2021, 72% of the electricity was provided by renewables, while a 2 am at a still night in June only 1%. Also, there is the problem of the “dark doldrums” whereby during a two-week period in January or February there is almost no renewable power at all.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Adjustments to the Power Grid

Resolving such problems will require a multitude of solutions.

-- large distance high voltage direct current (HVDC) lines need to be built connecting regions with different climate characteristics; such lines to be based on a new type of transistors: insulated gate bipolar transitors (IGDTs).

-- green hydrogen needs to play an increasing role as backstop and to provide support of seasonally changing renewable power supply

-- large low-cost storage systems are required and pumped storage needs to be expanded, and

-- energy demand needs to be managed more effectively.

ENERGY SUPPLY-DEMAND DEVELOPMENTS

Adjustments to the Power Grid

The massive increase in power supply by a factor four by 2050 as estimated by IEA in order to achieve net zero, needs to correspond with an expansion of the grid with a factor three.

It should be noted that grid expansion faces very significant political, regulatory and environmental hurdles. Therefore, very significant improvements are necessary in the various approval processes.

The development of the power grid will therefore face many obstacles. It is for this very reason that VME believes that net-zero will not be achieved by 2050 but may be achievable by 2070. This is in addition to the earlier comment under the Climate Change section of this presentation.

VME ENERGY FORECAST

IEA

The VME Energy Forecast is based on a modification of the IEA scenarios.

Following will be a discussion of the IEA Scenarios and the modification VME Energy makes to these forecast. These modifications are based on the previous discussions which indicate the huge importance of new technological and R&D developments.

The IEA forecast does not consider new technologies, the VME forecast does.

IEA ENERGY SCENARIOS

IEA

The framework for the VME Energy Forecast will be the World Energy Outlook, 2023, prepared by the International Energy Agency (IEA). This outlook contains three scenarios:

.. The Stated Policies Scenario (STEPS), reflect the policies under development by governments at this time.

.. The Announced Pledges Scenario (APS), which reflects new commitments made by countries in the context of COP27, and

.. The Net Zero Energy by 2050 Scenario (NZE), already discussed under Climate Change.

IEA ENERGY SCENARIOS

IEA

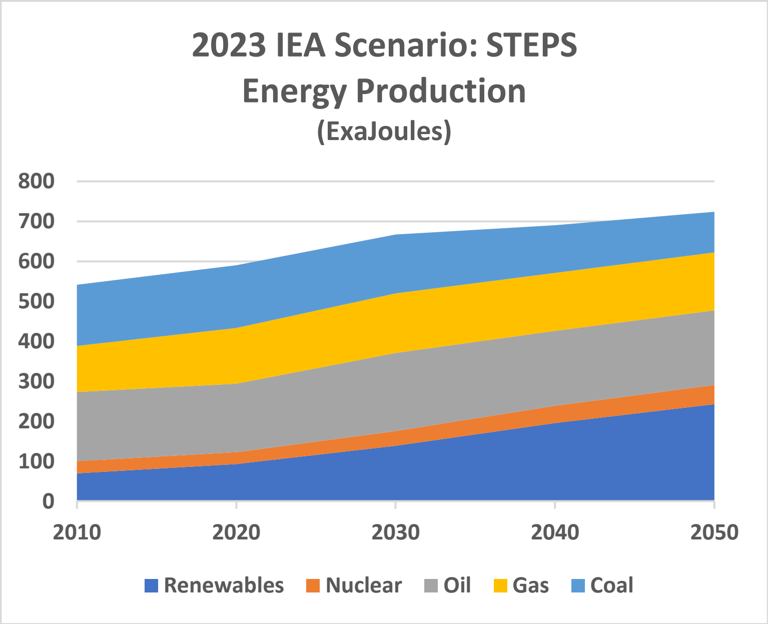
The IEA presents their overall energy forecasts in ExaJoules (EJ). For reference one Million Btu is 1.055 GigaJoules (a billion Joules). An ExaJoule is a billion GigaJoules.

First three slides will be presented displaying the energy production under the IEA scenarios. These scenarios all based on the assumption of 3.6% world economic growth per year until 2030 and 2.7% afterwards.

“Renewables” includes solar, wind, hydropower, bioenergy solids, liquids and gases as well as traditional use of biomass. “Oil” includes natural gas liquids.

IEA ENERGY SCENARIOS

2023 IEA Energy Production Scenario – STEPS

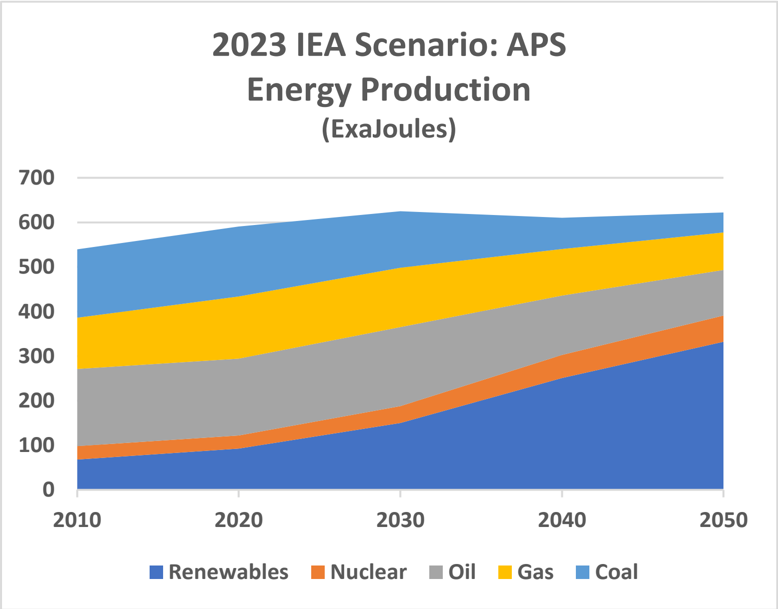


STEPS (EJ)	2010	2020	2030	2040	2050
Renewables	70	93	139	196	243
Nuclear	30	29	37	43	48
Oil	173	172	195	187	186
Gas	115	139	149	145	145
Coal	153	157	147	119	102
Total	541	591	667	690	724

The STEPS scenario involves 34% growth of overall energy production between 2010 and 2050. The scenario reaches 34% renewables by 2050. Oil production in 2050 is 7% higher than in 2010. Gas production is 23% higher. Coal is 34% lower. Nuclear power is 59% higher.

IEA ENERGY SCENARIOS

2023 IEA Energy Production Scenario – APS

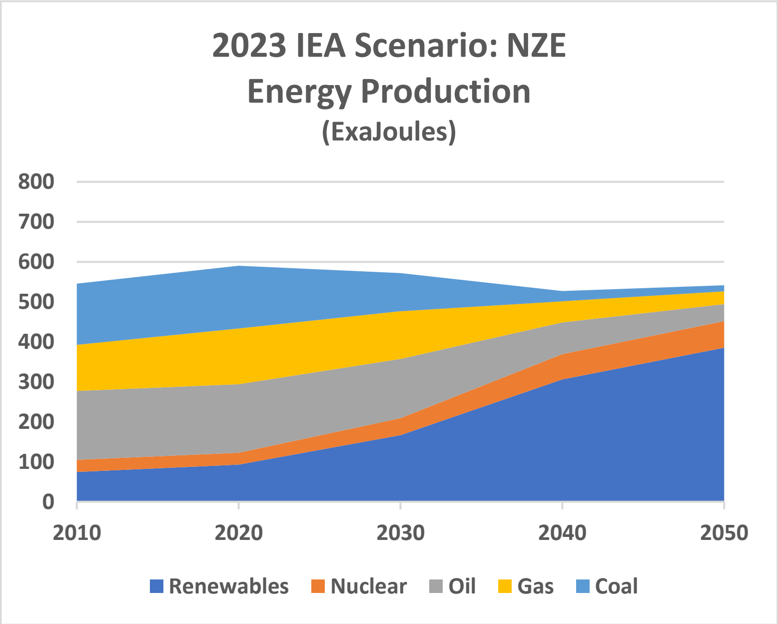


APS (EJ)	2010	2020	2030	2040	2050
Renewables	68	93	150	251	332
Nuclear	30	29	38	52	59
Oil	173	172	177	133	102
Gas	115	139	133	104	84
Coal	153	157	127	70	45
Total	539	591	625	610	622

The APS scenario involves only 15% growth of overall energy production between 2010 and 2050 due to increased emphasis on energy efficiency and electrification. The scenario reaches 53% renewables by 2050. Oil production in 2050 is 41% less. Gas production is 27% less. Coal is 71% lower. Nuclear power 96% higher.

IEA ENERGY FORECAST

2023 IEA Energy Production Scenario – NZE



NZE (EJ)	2010	2020	2030	2040	2050
Renewables	75	93	167	306	385
Nuclear	30	29	43	63	67
Oil	172	172	148	79	42
Gas	115	139	119	53	32
Coal	153	157	95	26	15
Total	545	591	572	527	541

After the high of 2020, the scenario contemplates an overall production decline. The scenario reaches 71% renewables by 2050. Oil production in 2050 is 75% less. Gas production is 72% less. Coal is 90% lower. Nuclear power increases with 122%.

BLOOMBERG NEF ENERGY FORECAST

Energy Production Forecast

The 2024 “New Energy Outlook” of Bloomberg NEF provide insights on what needs to be achieved to reach NetZero by 2050.

Following are some interesting points:

- The price tag will be $ 215 trillion
- Combined solar and wind capacity needs to be 31 TW. This will require tripling solar and wind between now and 2030 and subsequently tripling again between 2030 and 2050.
- Battery storage will need to be 4 TW, 50 times the level today.
- Power grids need to grow 111 million km, double of today.
- Land requirements for onshore solar and wind will be 2.9 million square km, 15 times the use of today.

VME ENERGY FORECAST

Energy Production Forecast

The IEA is portraying energy scenarios. None of these should be interpreted as forecasts.

Although scenarios are extremely useful for the design of petroleum policies and the related fiscal terms, it is also important to have forecasts. The terms and conditions of production sharing contracts and leases or licenses should ideally reflect the best possible forecast or range of forecasts of how the economic conditions affecting the petroleum arrangement may evolve.

Therefore, in the following slides a forecast is made based on the IEA scenarios, adjusted by analysis of Van Meurs Energy (VME) with the goal of forecasting a NetZero in 2070.

VME ENERGY FORECAST

Energy Production Forecast

The VME forecast is that NetZero will not be achieved by 2050 but maybe achieved by 2070 for the following reasons:

- **China, Brazil and some other nations only intent to reach NetZero by 2060, while India anticipates reaching it by 2070, it is unrealistic to assume that these nations will accelerate their plans.**
- **Most developing countries simply do not have the funds to finance such a strong transition, and developed countries are unwilling to provide most of this financing.**
- **There will be strong “not in my backyard” opposition to the major expansion of the electricity grid and other required energy projects, delaying most of the projects.**

VME ENERGY FORECAST

VME Energy Production Forecast

VME analysis indicates that the following adjustments must be made to the IEA scenarios to create a forecast:

1. **VME is of the view that some of the Announced Pledges will be realized, but not all. This would imply somewhat higher oil and gas production than in APS.**
2. **However, the VME projects a somewhat sharper decline of renewable prices and costs. Therefore, solar and wind will replace more aggressively gas and coal for power generation.**
3. **In total VME can therefore accept the APS energy scenario.**

VME ENERGY FORECAST

VME Energy Production Forecast

(continued)

4. VME forecasts a somewhat steeper decline of oil prices and therefore, biofuels production will be somewhat less (to be discussed later in more detail) due to increased competition.
5. VME assumes a slightly faster growth of nuclear
6. VME forecast a somewhat lower synfuels scenario of IEA as a forecast, because of lower oil prices.
7. VME accepts the IEA gas and coal forecasts with CCUS but includes additional low co0st abatement for natural gas.
8. VME extends the forecast to 2070
9. VME uses 2021 instead of 2020, since 2020 was an unusually low year.

VME ENERGY FORECAST

VME Energy Production Forecast

(continued)

10. The condensate production is based on a condensate yield of 15 barrels per Mcf.
11. Non-energy naphtha is based on current market conditions whereby 33% of the naphtha is used for petrochemical purposes with an aggressive growth rate to 2070.
12. By 2070 all naphta is assumed to be used for non-energy purposes (largely petrochemical industries).
13. Non-energy NGLs are based on the current market plus an aggressive forecast, by 2070 all NGLs are assumed to be non-energy.
14. The crude abatement is a best estimate.

VME ENERGY FORECAST

IEA World Energy Outlook 2023

The IEA published in October 2023 their World Energy Outlook 2023.

A very important change is that the IEA now indicates that even under the STEPS scenario coal, oil and natural gas demand will peak by 2030.

The APS scenario now estimates 623 EJ by 2050 instead of 639 EJ, with slight increases in production of renewables and nuclear, and modest drops in oil, coal and natural gas by 2050.

VME ENERGY FORECAST

VME Cost of Energy Production Forecast

VME FUTURE ENERGY COSTS (2023 $)							
		2020	2030	2040	2050	2060	2070
Solar	cents/kWh	3.2	2.5	2.0	1.7	1.6	1.5
Onshore Wind	cents/kWh	4.5	3.2	2.8	2.4	2.2	2.0
Fixed Offshore Wind	cents/kWh	6.5	5.0	4.4	4.0	3.7	3.5
Floating Wind	cents/kWh	9.0	6.4	5.6	5.0	4.7	4.5
Green Hydrogen	$/kg	5.00	2.40	1.60	1.20	1.04	0.92
	$/MMBtu	43.40	20.83	13.89	10.42	9.03	7.99
	$/BOE	250	120	80	60	52	46

The above table shows the VME estimate of future energy costs. This is an estimate of energy costs in the low-cost markets, since these markets effect the fossil fuels the most. The world average energy costs would be somewhat higher. In 2020 solar and onshore wind already provide cheaper electricity than can be provided by new fossil fuel plants. Between 2030 and 2040 fixed offshore wind will also become cheaper and by 2050 floating offshore wind may be cheaper than fossil fuel power generation. Hydrogen will become competitive between 2030 and 2040 and by 2050 it is likely that hydrogen can deliver energy cheaper than based on oil products for many applications. From 2050 onwards the world will move forward based on limitless, clean and cheap energy.

VME ENERGY FORECAST

VME Cost of Energy Production Forecast

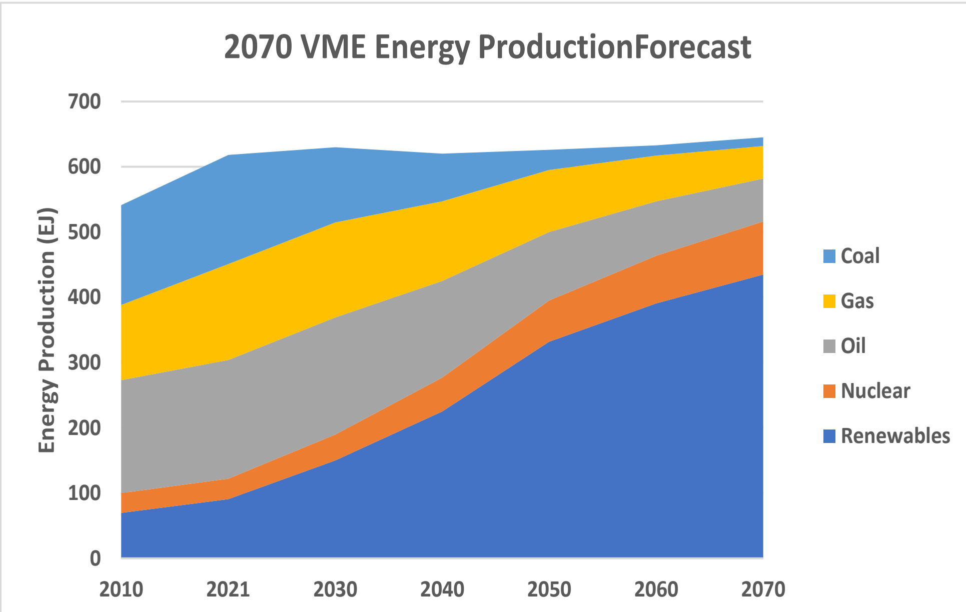
The above cost of energy forecast is subject to wide geographical variation and these cost must therefore be considered averages. For instance, the range of solar energy costs in 2020 was bout 2 – 10 cents/kWh, with the higher costs mainly in Europe. By 2050 the range may be 1 – 5 cents/kWh.

Similarly, there is a significant range for wind energy costs.

At the same time, due to technical developments costs may drop faster. Solar may reach 1.5 cents/kWh and floating wind 5 cents/kWh by 2030. Breakthroughs in hydrogen production costs may result in $ 1.00/kg by 2030 and $ 0.25/kg in 2050.

VME ENERGY FORECAST

VME 2070 Energy Production Forecast



VME (EJ)	2010	2021	2030	2040	2050	2060	2070
Renewables	70	91	150	225	332	391	435
Nuclear	30	31	40	52	63	73	81
Oil	173	182	179	148	105	83	66
Gas	115	147	146	122	95	70	50
Coal	153	167	115	73	31	16	13
Total	541	618	630	620	626	633	645

The forecast shows how renewables will grow strongly during the 2030-2050 period due to its low costs. However, due to pledges not being achieved gas and oil demand will stay initially somewhat higher. Coal production by 2050 is lower than in APS. By 2070 net zero is reached, with oil and gas production only for non-energy purposes, abated or with CCUS.

VME ENERGY FORECAST

VME 2070 Energy Production Forecast

VME (EJ)	2010	2021	2030	2040	2050	2060	2070
Solar	1	8	35	65	112	139	166
Wind	1	10	28	44	87	121	150
Hydro	12	15	18	23	27	31	34
Solid BioEn	23	31	48	65	74	71	61
Liquid BioEn	2	4	9	14	14	11	7
Gaseous BioEn	1	1	4	8	13	14	14
Traditional BioEn	25	22	8	6	5	4	3
Total Renewables	65	91	150	225	332	391	435
Nuclear	30	31	40	52	63	73	81
Unabated NatGas	115	146	141	108	70	33	0
Abated NatGas	0	1	5	14	25	37	50
Energy Oil	161	164	152	111	60	28	0
Biofuel and Synfuel	1	3	6	9	13	16	21
Abated Crude Oil	0	0	1	2	4	8	12
Non-Energy Oil	11	15	20	26	29	31	34
Unabated Coal	153	167	115	67	20	4	0
Coal with CCUS	0	0	0	6	11	12	13
Discrepancy	5	6	7	4	3	2	2
TOTAL	541	624	637	624	629	635	647

The forecast shows a very strong growth of solar and wind. Also, the growth of nuclear is strong. By 2070 net zero is reached, with oil production only abated or for non-energy purposes and no unabated gas and coal production.

VME ENERGY FORECAST

VME Energy/Capita Forecast

VME	2021	2030	2040	2050	2060	2070
Total EJ	618	630	620	626	633	649
World Population (Billion)	7.9	8.5	9.2	9.7	9.9	10.1
GigaJoule/Capita	78	74	67	65	64	64
World GDP (Trillion US $)	87	108.9	139.4	178.5	228.5	292.5
MegaJoule/US$	7.0	5.7	4.5	3.6	2.8	2.1

An interesting aspect of the VME forecast is that the energy consumption per capita will decrease between 2021 and 2070, from 79 to 64 GigaJoules/Capita while the energy consumption per US $ GDP will drop from 7.0 to 2.1 MegaJoules/US $. The world population forecast is based on the 2022 UN median forecast. The GDP growth is assumed to be a modest 2.5% per year.

The reason is that the adoption of solar and wind in power plants over fossil fuels and from ICE's to EVs prevents very significant energy conversion losses. Also, in general there will be significant increases in energy efficiency and GDP will move increasingly from manufacturing to services.

VME ENERGY FORECAST

Climate Change Effects – Tripling Clean Energy

During COP28 a group of 118 countries agreed to triple clean energy supplies by 2030.

The group includes, the EU, USA, Brazil, UAE, Australia, Nigeria, Japan and Canada, but not China and India.

Also, a group of 20 nations agreed to triple nuclear energy by 2050.

From the VME forecast it will be clear that if these objectives would be achieved that this would represent a major change in the future of world energy.

However, the previous VME forecast indicates that these objectives will not be achieved.

VME ENERGY FORECAST

Coal Demand

The IEA STEPS and APS forecast and the VME forecast all indicate a use of coal in 2030 that is less than 2020.

The year 2023 saw the highest coal demand on record of 8.5 billion tons. Energy demand for coal may decline slightly in the coming two years, but industrial demand will grow. China, India and South-East Asia account for 75% of the world coal consumption.

VME ENERGY FORECAST

Oil Production Forecasts

The IEA also makes scenarios of the future oil production in the framework of the energy scenarios.

Interestingly, obviously for political reasons the IEA does not make a forecast how the world oil production will be distributed under the NZE scenario. This would create political issues as to how much oil OPEC would still produce under this scenario, and which Non-OPEC countries would cut production the most.

VME ENERGY FORECAST

Oil Production and Demand Forecasts

Following are the IEA scenarios for the STEPS and the APS case and my interpretation of how the IEA NZE scenario would result in oil production levels.

I also interpolated the 2040 production levels.

Following are the details of the STEPS and APS scenarios for supply and demand. The difference between supply and demand for any regions considered exports or imports. For oil the supply and demand is for all liquids.The original NZE scenario in terms of oil production will also be provided.

The forecasts are based on the 2022 liquids scenarios. No liquids forecasts were provided in 2023 and therefore the 2022 will serve as background.

VME ENERGY FORECAST

2022 IEA STEPS Oil Production and Demand Scenario

STEPS	LIQUIDS SUPPLY (million barrels per day)				
	2010	2020	2030	2040	2050
Processing Gains	2.2	2.1	2.6	2.8	3.0
Conventional crude	66.8	59.7	62.5	62.5	62.6
Tight Oil	0.7	7.3	10.9	10.4	9.9
Natural gas liquids	12.7	17.9	20.9	20.0	19.3
Extra heavy oil	2.6	3.4	4.4	5.4	6.2
Biofuels	1.0	2.0	3.4	4.5	5.3
Synthetic Fuel	0.0	0.0	0.0	0.1	0.2
Other	0.6	0.8	1.2	1.2	1.3
TOTAL	86.6	93.2	105.9	106.9	107.8
Biofuel and Synthetic	1.0	2.0	3.4	4.6	5.5
North America	14.2	23.8	28.6	26.7	24.6
Central and South America	7.4	5.9	9.0	10.3	11.4
Europe	4.4	3.8	3.1	2.3	1.3
Africa	10.2	7.0	7.0	6.5	6.1
Middle East	25.4	27.7	33.9	36.9	40.4
Russia	10.5	10.7	9.5	9.1	8.6
Other Eurasia	2.9	2.7	2.4	2.2	2.0
Asia Pacific	8.4	7.5	6.3	5.5	4.8
Non-OPEC	50.0	58.3	64.0	58.1	56.2
OPEC	33.4	30.8	35.9	41.4	43.1

The STEPS scenario shows how oil production would continue to increase during the next decade, but thereafter would stabilize. It is expected that Non-OPEC production would decline after 2030, while OPEC production would continue to increase. Also, the production of South America would continue to increase. The forecast indicates a significant increase of biofuels and the start of hydrogen based synfuel production.

VME ENERGY FORECAST

2022 IEA STEPS Oil Production and Demand Scenario

STEPS	LIQUIDS DEMAND (million barrels per day)				
	2010	2020	2030	2040	2050
Biofuel and Synthetic	1.0	2.0	3.4	4.6	5.5
North America	22.2	20.1	20.5	18.3	16.2
Central and South America	5.5	4.9	5.5	5.7	5.8
Europe	13.9	11.9	10.9	8.7	7.1
Africa	3.3	3.6	5.0	7.0	8.5
Middle East	7.1	7.4	8.8	9.9	10.9
Russia	3.0	3.1	3.3	3.4	3.5
Other Eurasia	0.7	0.7	0.9	1.0	1.1
Asia Pacific	25.0	31.4	38.2	37.5	36.7
International Bunkers	7.1	5.8	9.3	10.8	12.4

The STEPS demand scenario shows how oil demand would start to decline after 2030 in North America, Europe and Asia Pacific. Oil demand in other regions would continue to increase. Biofuels would make an important contribution.

VME ENERGY FORECAST

2022 IEA STEPS Oil Production and Demand Scenario

STEPS	LIQUIDS TRADE(million barrels per day)				
	2010	2020	2030	2040	2050
Biofuel and Synthetic	0.0	0.0	0.0	0.0	0.0
North America	-8.0	3.7	8.1	8.4	8.4
Central and South America	1.9	1.0	3.5	4.6	5.6
Europe	-9.5	-8.1	-7.8	-6.4	-5.8
Africa	6.9	3.4	2.0	-0.5	-2.4
Middle East	18.3	20.3	25.1	27.0	29.5
Russia	7.5	7.6	6.2	5.7	5.1
Other Eurasia	2.2	2.0	1.5	1.2	0.9
Asia Pacific	-16.6	-23.9	-31.9	-32.0	-31.9
International Bunkers	-7.1	-5.8	-9.3	-10.8	-12.4
Process Gain	2.2	2.1	2.6	2.8	3.0
TOTAL	-2.2	2.3	0.0	0.0	0.0

The resulting trade scenario based on STEPS production and demand indicates the continuation of a robust international trade increasing from 37.8 million barrels per day in 2020 to 52.5 million barrels per day in 2050.

VME ENERGY FORECAST

2022 IEA APS Oil Production and Demand Scenario

APS	LIQUIDS SUPPLY (million barrels per day)				
	2010	2020	2030	2040	2050
Processing Gains	2.2	2.1	2.3	2.1	1.9
Conventional crude	66.8	59.7	56.8	44.0	31.0
Tight Oil	0.7	7.3	9.7	8.4	6.7
Natural gas liquids	12.7	17.9	19.2	16.2	13.9
Extra heavy oil	2.6	3.4	4.1	3.8	3.4
Biofuels	1.0	2.0	5.5	7.3	9.2
Synthetic Fuel	0.0	0.0	0.2	2.0	3.2
Other	0.6	0.8	0.9	0.6	0.3
TOTAL	86.6	93.2	98.7	84.4	69.6
Biofuel and Synthetic	1.0	2.0	5.7	9.3	12.4
North America	14.2	23.8	25.8	20.5	14.7
Central and South America	7.4	5.9	8.3	7.5	6.5
Europe	4.4	3.8	2.7	1.8	0.6
Africa	10.2	7.0	5.8	4.5	2.9
Middle East	25.4	27.7	31.2	26.7	22.9
Russia	10.5	10.7	9.0	6.2	4.0
Other Eurasia	2.9	2.7	2.2	1.8	1.4
Asia Pacific	8.4	7.5	5.7	4.0	2.2
Non-OPEC	50.0	58.3	58.2	45.0	31.6
OPEC	33.4	30.8	32.5	28.0	23.7

The APS scenario shows how oil production would start to decrease after 2030, despite strong increases in biofuels and synfuels. Oil production would decrease in all areas of the world, including the Middle East. Also, OPEC production would decrease after 2030.

VME ENERGY FORECAST

2022 IEA APS Oil Production and Demand Scenario

APS	LIQUIDS DEMAND (million barrels per day)				
	2010	2020	2030	2040	2050
Biofuel and Synthetic	1.0	2.0	5.7	9.3	12.4
North America	22.2	20.1	18.3	13.9	6.7
Central and South America	5.5	4.9	4.8	3.9	2.4
Europe	13.9	11.9	9.2	5.0	2.7
Africa	3.3	3.6	4.9	5.1	6.1
Middle East	7.1	7.4	8.0	8.0	7.9
Russia	3.0	3.1	3.3	3.2	3.1
Other Eurasia	0.7	0.7	0.8	0.8	0.8
Asia Pacific	25.0	31.4	35.1	27.4	20.6
International Bunkers	7.1	5.8	8.6	7.8	6.8
TOTAL	88.8	90.9	98.7	84.4	69.5

The APS demand scenario shows how oil demand would start to decline after 2030 in North America, Central and South America, Europe and Asia Pacific. Oil demand increases in Africa and stabilizes in the other regions, including the Middle East.

VME ENERGY FORECAST

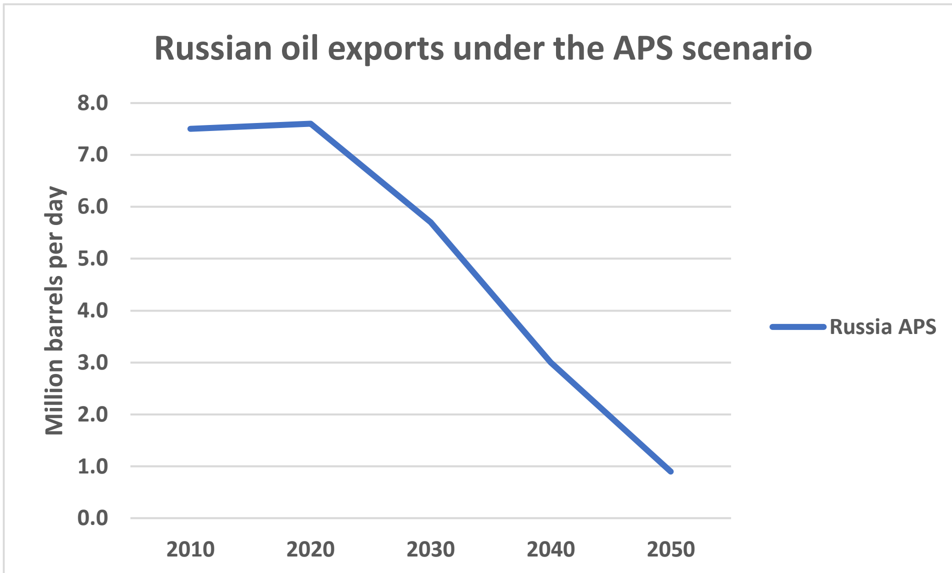
2022 IEA APS Oil Production and Demand Scenario

APS	LIQUIDS TRADE(million barrels per day)				
	2010	2020	2030	2040	2050
Biofuel and Synthetic	0.0	0.0	0.0	0.0	0.0
North America	-8.0	3.7	7.5	6.6	8.0
Central and South America	1.9	1.0	3.5	3.6	4.1
Europe	-9.5	-8.1	-6.5	-3.2	-2.1
Africa	6.9	3.4	0.9	-0.6	-3.2
Middle East	18.3	20.3	23.2	18.7	15.0
Russia	7.5	7.6	5.7	3.0	0.9
Other Eurasia	2.2	2.0	1.4	1.0	0.6
Asia Pacific	-16.6	-23.9	-29.4	-23.4	-18.4
International Bunkers	-7.1	-5.8	-8.6	-7.8	-6.8
Process Gain	2.2	2.1	2.3	2.1	1.9
TOTAL	-2.2	2.3	0.0	0.0	0.0

The resulting trade scenario based on APS production and demand indicates an increase in international trade increasing from 37.8 million barrels per day in 2020 to 44.5 million barrels per day in 2030 and a decline after 2030 to a level of only 30.5 million barrels per day in 2050.

VME ENERGY FORECAST

2022 IEA APS Oil Production and Demand Scenario: Russia



Quite an astonishing result of the APS scenario is the elimination of Russia as an exporter of oil and liquids as can be seen in the chart above.

VME ENERGY FORECAST

IEA Oil Production Scenarios

NZE	OIL SUPPLY (million barrels per day)				
	2010	2020	2030	2040	2050
Processing Gains	2.2	2.1	1.9	1.1	0.5
Non-OPEC	50.1	58.3	46.0	23.0	12.0
OPEC	33.3	30.9	25.5	18.2	10.0
TOTAL	85.5	91.3	73.4	42.3	22.5
North America	14.2	23.8	20.1	10.5	5.6
Central and South America	7.4	5.9	3.8	1.9	1.2
Europe	4.4	3.8	2.6	1.2	0.4
Africa	10.2	7.0	6.0	3.7	2.2
Middle East	25.4	27.7	23.0	16.5	8.5
Eurasia	13.4	13.4	11.0	4.9	2.2
Asia Pacific	8.5	7.5	5.0	2.4	1.9

Using the IEA energy NZE scenario, VME attempted to allocate reasonably the very low oil production in 2050. It is the VME view that few Non-OPEC countries would elect to stop issuing licenses. Bidding rounds may still go on for many years. This would result in still significant oil production in Non-OPEC countries. This would put OPEC in a position where the level of oil production would be far below the current level. This raises indeed interesting questions.

It should also be mentioned that most of the oil production in 2050 will be used as feedstock for petrochemical non-energy purposes.

VME ENERGY FORECAST

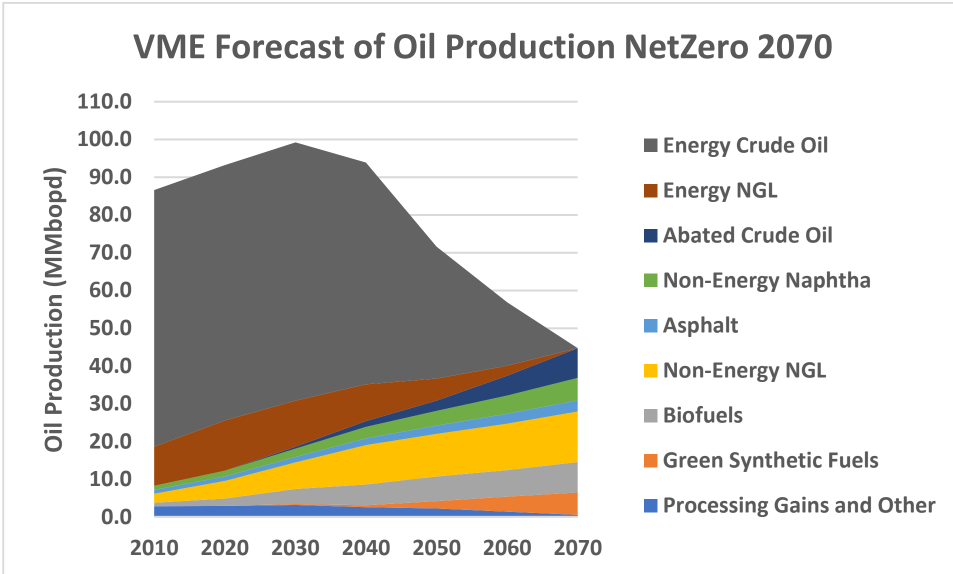
OPEC Oil Demand Forecast

OPEC Long Term Oil Demand (million barrels of oil per day)				
	2022	2030	2040	2045
OECD Americas	25.0	25.8	23.2	21.5
OECD Europe	13.5	13.1	10.8	9.8
OECD Asia-Pacific	7.4	7.2	6.0	5.4
OECD TOTAL	45.9	46.0	40.0	36.7
China	14.9	17.8	18.5	18.8
India	5.1	7.3	10.2	11.7
Other Asia	9.0	11.1	12.9	13.6
Latin America	6.4	7.8	8.7	9.0
Middle East	8.3	10.0	11.4	11.9
Africa	4.4	5.9	7.4	8.2
Russia	3.6	4.0	3.9	3.9
Other Eurasia	1.2	1.3	1.5	1.5
Other Europe	0.8	0.9	0.8	0.8
NON-OECD TOTAL	53.6	66.0	0.4	79.4
WORLD	99.6	112.0	115.4	116.0

The OPEC oil demand forecast is derived from the "2023 World Oil Outlook 2045" published by OPEC. OPEC estimates large demand increases for India, China, Other Asia, Africa and the Middle East. Please note that the definition of "oil" seems to be different from IEA since the 2022 demand figures do not match, resulting in more "oil".

VME ENERGY FORECAST

VME oil forecast overview



The chart shows the NetZero 2070 VME forecast for oil production.

By 2070 the 45 million barrels per day of oil production will consist of conventional abated oil (including CCS), asphalt, natural gas liquids, non-energy naphtha, biofuels and green synfuel. The non-energy naphtha and NGLs will be used as non-energy feedstock for petrochemical industries and other purposes, while other uses will be for energy purposes such as SAF for air transportation and e-methanol for shipping. By 2070 there will be no further Energy Crude Oil or Energy NGL.

VME ENERGY FORECAST

VME Oil Production and Demand Scenario

VME	LIQUIDS SUPPLY (million barrels per day)						
	2010	2020	2030	2040	2050	2060	2070
Processing Gains	2.2	2.1	2.3	2.0	1.9	1.2	0.3
Conventional crude	57.3	53.9	53.2	48.7	29.9	20.2	14.5
Condensate Production	9.5	5.8	6.2	5.6	4.4	3.2	2.3
Tight Oil	0.7	7.3	9.4	7.8	6.7	4.0	0.0
Natural gas liquids	12.7	17.9	19.2	20.2	17.1	15.0	13.4
Extra heavy oil	2.6	3.4	3.8	3.0	2.8	2.0	0.0
Biofuels	1.0	2.0	4.0	5.5	6.5	7.0	8.0
Green Synthetic Fuel	0.0	0.0	0.2	0.5	2.0	4.0	6.0
Other	0.6	0.8	0.9	0.6	0.3	0.2	0.2
TOTAL	86.6	93.2	99.2	93.9	71.6	56.8	44.7
Biofuel and Synthetic	1.0	2.0	4.2	6.0	8.5	11.0	14.0
North America	14.2	23.8	23.5	20.0	12.0	8.5	5.7
Central and South America	7.4	5.9	8.3	10.0	7.0	4.5	1.5
Europe	4.4	3.8	2.5	1.5	0.5	0.2	0.0
Africa	10.2	7.0	7.6	8.0	6.5	5.0	4.0
Middle East	25.4	27.7	34.0	33.9	28.2	21.4	15.2
Russia	10.5	10.7	9.8	7.7	4.3	3.5	2.5
Other Eurasia	2.9	2.7	2.7	2.3	1.6	1.2	0.8
Asia Pacific	8.4	7.5	6.6	4.5	3.0	1.5	1.0
Non-OPEC Crude Oil	50.0	58.3	60.8	55.3	39.6	32.5	27.1
OPEC Crude Oil	33.4	30.8	38.4	38.6	32.0	24.3	17.6

The VME scenario shows how oil production would start to decrease after 2030, rather like to the APS scenario. OPEC production will decline sharply after 2040. This will have an important impact on oil prices.

VME ENERGY FORECAST

VME Oil Production and Demand Scenario

VME	LIQUIDS DEMAND (million barrels per day)						
	2010	2020	2030	2040	2050	2060	2070
Biofuel and Synthetic	1.0	2.0	4.2	6.0	8.5	11.0	14.0
North America	22.2	20.1	18.3	15.4	7.7	4.7	1.4
Central and South America	5.5	4.9	5.8	6.4	3.4	2.5	1.1
Europe	13.9	11.9	9.2	6.5	4.7	2.5	1.2
Africa	3.3	3.6	4.9	6.1	6.1	5.0	4.0
Middle East	7.1	7.4	8.5	9.0	7.9	6.5	4.8
Russia	3.0	3.1	3.3	3.5	3.1	2.8	2.4
Other Eurasia	0.7	0.7	0.8	0.8	0.8	0.8	0.8
Asia Pacific	25.0	31.4	35.6	32.4	22.6	15.5	10.5
International Bunkers	7.1	5.8	8.6	7.8	6.8	5.5	4.5
TOTAL	88.8	90.9	99.2	93.9	71.6	56.8	44.7

The VME demand scenario shows how oil demand would start to decline after 2030 in North America, Central and South America, Europe and Asia Pacific. Oil demand increases in Africa and stabilizes in the other regions, including the Middle East. Decline will be very strong in North America, Europe and Asia Pacific after 2030, except for non-energy demand.

VME ENERGY FORECAST

VME Oil Production and Demand Scenario

VME	LIQUIDS TRADE (million barrels per day)						
	2010	2020	2030	2040	2050	2060	2070
Biofuel and Synthetic	0.0	0.0	0.0	0.0	0.0	0.0	0.0
North America	-8.0	3.7	5.2	4.6	4.3	3.8	4.3
Central and South America	1.9	1.0	2.5	3.6	3.6	2.0	0.4
Europe	-9.5	-8.1	-6.7	-5.0	-4.2	-2.3	-1.2
Africa	6.9	3.4	2.7	1.9	0.4	0.0	0.0
Middle East	18.3	20.3	25.5	24.9	20.3	14.9	10.4
Russia	7.5	7.6	6.5	4.2	1.2	0.7	0.1
Other Eurasia	2.2	2.0	1.9	1.5	0.8	0.4	0.0
Asia Pacific	-16.6	-23.9	-29.0	-27.9	-19.6	-14.0	-9.5
International Bunkers	-7.1	-5.8	-8.6	-7.8	-6.8	-5.5	-4.5
TOTAL TRADE	36.8	38.0	44.3	40.7	30.6	21.8	15.2

The resulting trade scenario based on VME production and demand indicates an increase in international trade increasing from 37.8 million barrels per day in 2020 to 44.3million barrels per day in 2030 and a decline after 2030 to a level of only 30.6 million barrels per day in 2050. By 2070 the Middle East and Canada will be the only exporters of relatively modest volumes of oil, apart from possible small exports from Russia.

VME ENERGY FORECAST

Gas Production and Demand Forecasts

Following are the IEA scenarios for the STEPS and the APS case of world gas production and demand.

I also interpolated the 2040 production and demand levels.

Subsequently the VME forecast is provided.

VME ENERGY FORECAST

STEPS Gas Production and Demand Scenario

STEPS	GAS SUPPLY (billion cubic meters)				
	2010	2020	2030	2040	2050
North America	811	1165	1283	1141	1017
Central and South America	160	154	149	180	195
Europe	341	241	247	218	208
Africa	203	237	313	339	369
Middle East	463	646	853	960	1030
Russia	657	716	633	620	612
Other Eurasia	150	195	198	220	245
Asia Pacific	489	639	694	683	678
TOTAL	3274	3993	4370	4361	4355

The STEPS gas production scenario seems supply stabilizing from 2030, with some regions such as North America and Europe declining production and some other regions such Africa and the Middle East increasing production afterwards.

VME ENERGY FORECAST

STEPS Gas Production and Demand Scenario

STEPS	GAS DEMAND (billion cubic meters)				
	2010	2020	2030	2040	2050
North America	835	1096	1118	965	820
Central and South America	148	148	159	170	179
Europe	696	596	511	445	395
Africa	106	164	215	255	292
Middle East	391	554	689	750	833
Russia	472	496	498	484	470
Other Eurasia	102	115	128	146	165
Asia Pacific	576	859	1043	1125	1173
International Bunkers	0	1	11	25	30
TOTAL	3326	4029	4372	4365	4357

The STEPS gas demand scenario also contemplates a stabilization of gas demand after 2030. Some regions such as North America and Europe see a strong decline in gas demand afterwards. Other regions see a growth or stabilizing gas demand.

VME ENERGY FORECAST

STEPS Gas Production and Demand Scenario

STEPS	GAS TRADE (billion cubic meters)				
	2010	2020	2030	2040	2050
North America	-24	69	165	176	197
Central and South America	12	6	-10	10	16
Europe	-355	-355	-264	-227	-187
Africa	97	73	98	84	77
Middle East	72	92	164	210	197
Russia	185	220	135	136	142
Other Eurasia	48	80	70	74	80
Asia Pacific	-87	-220	-349	-442	-495
International Bunkers	0	-1	-11	-25	-30
TOTAL	-52	-36	-2	-4	-3

The resulting trade scenario based on STEPS gas production and demand indicates an increase in a robust international trade increasing from 576 billion cubic meters in 2020 to 712 billion cubic meters by 2050, based on pipeline exports and LNG trade.

VME ENERGY FORECAST

APS Gas Production and Demand Scenario

APS	GAS SUPPLY (billion cubic meters)				
	2010	2020	2030	2040	2050
North America	811	1165	1098	810	485
Central and South America	160	154	133	118	95
Europe	341	241	176	122	65
Africa	203	237	281	265	239
Middle East	463	646	798	754	690
Russia	657	716	584	533	483
Other Eurasia	150	195	167	170	172
Asia Pacific	489	639	636	545	432
TOTAL	3274	3993	3873	3317	2660

The APS gas supply shows declines in all regions except for Other Eurasia where supply would be stabilizing. Sharp declines in gas supply occur in North America and Europe.

VME ENERGY FORECAST

APS Gas Production and Demand Scenario

APS	GAS DEMAND (billion cubic meters)				
	2010	2020	2030	2040	2050
North America	**835**	**1096**	**933**	**667**	**396**
Central and South America	**148**	**148**	**141**	**121**	**96**
Europe	**696**	**596**	**394**	**278**	**122**
Africa	**106**	**164**	**189**	**191**	**193**
Middle East	**391**	**554**	**638**	**615**	**582**
Russia	**472**	**496**	**470**	**448**	**424**
Other Eurasia	**102**	**115**	**117**	**112**	**108**
Asia Pacific	**576**	**859**	**983**	**877**	**731**
International Bunkers	**0**	**1**	**8**	**8**	**8**
TOTAL	**3326**	**4029**	**3873**	**3317**	**2660**

The APS gas demand shows declines of gas demand in all regions, except for Africa where demand would stabilize. Sharp declines in demand occur in North America and Europe.

VME ENERGY FORECAST

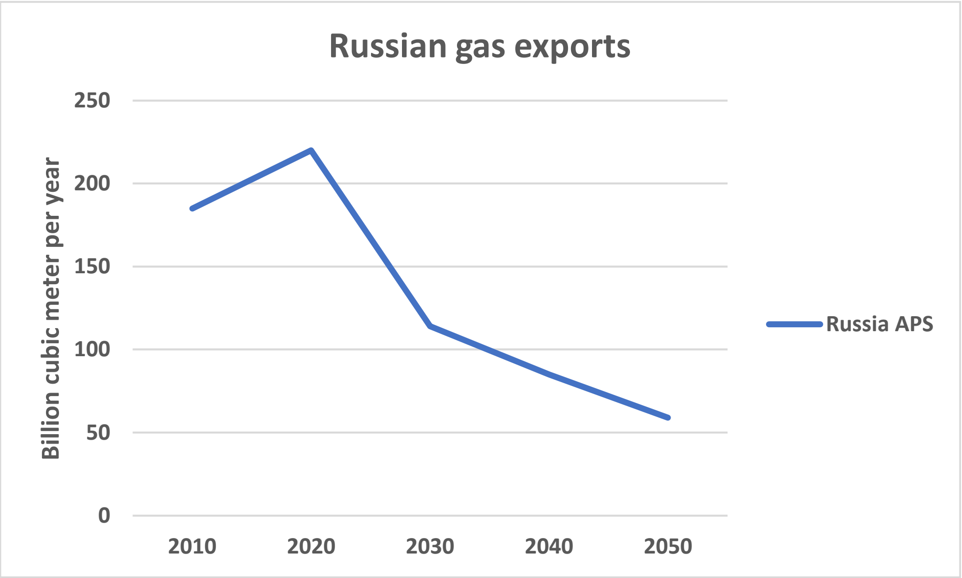
APS Gas Production and Demand Scenario

APS	GAS TRADE (billion cubic meters)				
	2010	2020	2030	2040	2050
North America	-24	69	165	143	89
Central and South America	12	6	-8	-3	-1
Europe	-355	-355	-218	-156	-57
Africa	97	73	92	74	46
Middle East	72	92	160	139	108
Russia	185	220	114	85	59
Other Eurasia	48	80	50	58	64
Asia Pacific	-87	-220	-347	-332	-299
International Bunkers	0	-1	-8	-8	-8
TOTAL	-52	-36	0	0	0

The result of the APS gas supply and demand shows how trade in natural gas would be declining from 576 billion cubic meters in 2020 to 356 billion cubic meters by 2050. Again there is a remarkable decline of Russian gas exports.

VME ENERGY FORECAST

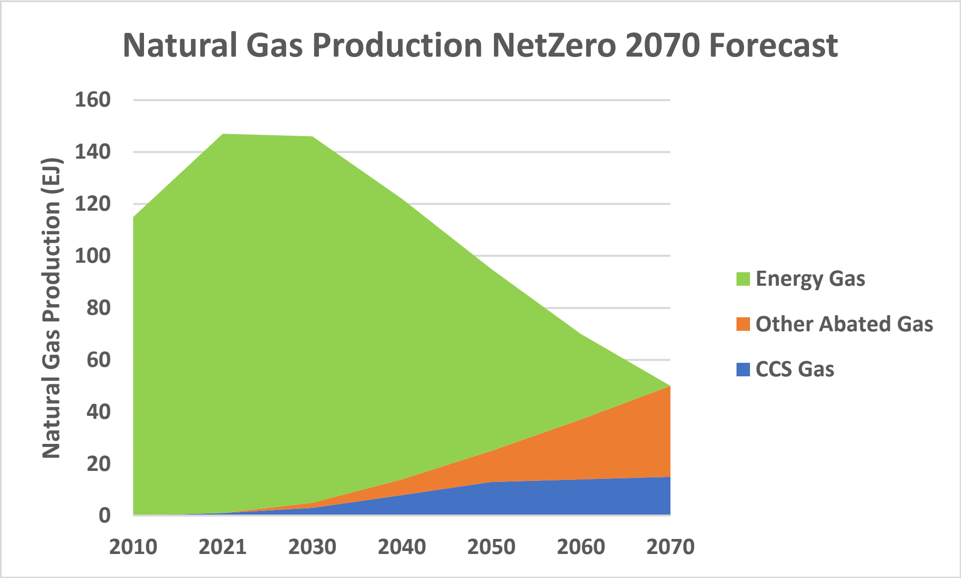
APS Gas Production and Demand Scenario: Russia



The above chart shows the remarkable decline of Russian gas exports, based on the APS scenario.

IMPACTS ON THE PETROLEUM INDUSTRY

VME Gas Production and Demand Scenario



The VME scenario shows how by 2070 net zero will be reached. Gas production will be gas that is subject to CCS (the IEA scenario was used) and other abatement methods.

VME ENERGY FORECAST

VME Gas Production and Demand Scenario

VME	GAS SUPPLY (Tcf per year)						
	2010	2020	2030	2040	2050	2060	2070
North America	29	41	42	41	26	18	12
Central and South America	6	5	6	6	5	3	3
Europe	12	9	4	3	1	1	0
Africa	7	8	11	10	8	6	5
Middle East	16	23	37	36	30	25	19
Russia	23	25	21	17	12	7	5
Other Eurasia	6	7	7	7	5	4	2
Asia Pacific	17	23	23	21	18	14	9
TOTAL	116	141	152	137	106	78	56

Overall, the VME forecast of gas supply declines somewhat faster than the APS scenario, since VME assumes somewhat lower prices for solar and wind. The VME gas supply shows declines in all regions. Sharp declines in gas supply occur in North America and Europe. By 2070 the world natural gas supply will be much reduced, except for gas production that is subject to CCS and other abatement.

VME ENERGY FORECAST

VME Gas Production and Demand Scenario

GAS DEMAND (Tcf per year)

	2010	2020	2030	2040	2050	2060	2070
North America	29	39	41	40	26	18	12
Central and South America	5	5	6	6	5	3	3
Europe	25	21	15	9	3	1	0
Africa	4	6	9	9	8	6	5
Middle East	14	20	23	23	23	21	17
Russia	17	18	17	15	11	7	5
Other Eurasia	4	4	5	4	4	3	2
Asia Pacific	20	30	36	33	26	18	11
International Bunkers	0	0	0	0	0	0	0
TOTAL	117	142	152	140	106	78	56

The VME gas demand shows declines of gas demand in all regions, except for Africa where demand would stabilize. Sharp declines in demand occur in North America, Europe and Asia Pacific due to the strong competition of cheap renewables.

VME ENERGY FORECAST

VME Gas Production and Demand Scenario

VME	GAS TRADE (Tcf per year)						
	2010	2020	2030	2040	2050	2060	2070
North America	-1	2	1	1	0	0	0
Central and South America	0	0	0	0	0	0	0
Europe	-13	-13	-11	-6	-2	0	0
Africa	`	3	2	1	0	0	0
Middle East	3	3	14	13	7	4	2
Russia	7	8	4	2	1	0	0
Other Eurasia	2	3	3	2	1	1	0
Asia Pacific	-3	-8	-13	-12	-8	-4	-2
International Bunkers	0	0	0	0	0	0	0
TOTAL	17	21	24	18	10	4	2

The result of the gas supply and demand forecast of VME is a world trading situation where trade initially increases from 576 billion cubic meters to 633 billion cubic meters in 2030 and subsequently declines to 249 billion cubic meters by 2050. By 2070 world LNG trade will be very limited, with only Qatar and some other Middle East countries exporting to AsiaPacific.

VME ENERGY FORECAST

Ember Energy Analysis of Electricity and IEA Forecast

A highly interesting study was recently published by Ember Energy (London, UK) (April 2023).

They predict that the year 2022 will be the year of maximum use of fossil fuels for power generation on a worldwide basis. This is entirely due to the 19% increase in solar and wind generation. Furthermore, in its 2024 analysis Ember concluded that the world passed the 30% level in renewable energy use for power generation.

The IEA in the Mid Term forecast concludes that 2023 will be the year of maximum gasoline consumption, due to increased use of EVs. IEA forecasts that total world oil demand will start to decline after 2030.

VME ENERGY FORECAST

Forecast of crude oil price

Currently oil prices have returned to pre-2020 levels.

Following is the VME evaluation of the oil price forecast based on an analysis of oil reserves and liquid production.

It is assumed that the United States and Canada will be able to maintain a shale oil production of 6 Mmbopd, but that industry assessments of future prices do not encourage increases in production. Enough wells need to be drilled to substitute the production of shale oil wells that typically decline rather fast.

VME ENERGY FORECAST

Forecast of oil price – reduction of role of fossil fuels

The crude oil industry will gradually transform from an industry producing fossil fuels to producing feedstock, primarily, LPG, ethane and naphta for the petrochemical industries.

It is estimated that the petroleum production for feedstock production will increase from about 14% today to 37% by 2050 and as indicated in an earlier slide, by 2070 the world petroleum production will be almost exclusively for feedstock.

As mentioned before the natural gas industry will probably loose its role in producing ammonia and methanol to green hydrogen.

VME ENERGY FORECAST

Forecast of crude oil price – wide range

The previous projection is obviously subject to a wide margin of uncertainty. World oil and gas demand could be higher or lower.

For instance, WoodMac predicts that the oil price in 2050 could be as low at $ 10/bbl.

As discussed, hydrogen or biofuels could play a far more important role than assumed or the role could be less.

It might be that there would still a significant expansion of shale oil and shale gas production in the US and Canada.

However, also other shale projects could see significant expansion. For instance, ARAMCO is investing $ 10 billion to develop the huge Jafirah shale gas project in Saudi Arabia, estimates to produce 2 Bcf per day of gas and 630,000 barrels per day of natural gas liquids and condensates.

VME ENERGY FORECAST

Forecast of crude oil price – wide range

An important factor of uncertainty is Non-OPEC crude oil production. It is assumed that the lower price will result in less exploration activity and therefore a gradual decline of production. However, future improvements in technologies and unexpected large discoveries of oil and gas could change this picture completely.

Also, VME expects governments of most Non-OPEC countries to continue to strongly support new licensing rounds for the exploration and development of oil and gas.

VME ENERGY FORECAST

Forecast of crude oil price – new technologies

The improvements in technology are in particular important for the drilling of producer wells in North America. Wells used to be vertical steel pipes with oil and gas flowing in at the bottom.

Today oil and gas producer wells look more like upside down trees with laterals being drilled in all directions and subsequently fracking applied to the various reservoirs that are being tapped.

This makes it possible to rapidly increase production by re-entering and re-drilling existing wells and thereby significantly increasing the recovery factor from existing reservoirs.

This therefore has a significant constraining impact on increases in the oil price, since immediate production increases will be the result of an oil price increase.

VME ENERGY FORECAST

Forecast of crude oil price – new technologies

The logical conclusion of the new drilling technologies is that also the related fiscal systems need to change.

Alberta has taken the lead on this by introducing the so-called *"Modernized Royalty Framework"* in 2017.

This new framework consist of a low royalty before payout per well. Payout is determined by the following variables:

-- true vertical depth

-- total lateral depth, and

-- total proppant placed equivalent (being the equivalent of different types of proppant used for fracking).

VME ENERGY FORECAST

Forecast of crude oil price – Proved Oil Reserves

WORLD OIL RESERVES BASED ON BP (end of 2019)		
	(billion barrels)	R/P Ratio
Canada	169.7	82.3
Mexico	5.8	8.3
United States	68.9	11.1
Brazil	12.7	12.1
Venezuela	303.8	xx
Norway	8.5	13.5
UK	2.7	6.6
Russia	107.2	25.5
Iran	155.6	120.6
Iraq	145.1	83.1
Kuwait	101.5	92.8
Saudi Arabia	297.6	68.9
UAE	97.8	67.1
Libya	48.4	107.9
Nigeria	37.1	48.1
China	26.2	18.7
Total World	1733.9	49.9
OPEC	1214.7	93.6
Russia	107.2	25.5
Canada oil sands	163.5	xx
Other Non-OPEC	248.5	14.2

Of importance in understanding future oil developments are the available proved oil reserves and the Reserve/Production ratios for the various countries. The world has 50 years of proved reserves based on the information of the BP statistical review. The BP estimate includes gas condensates and NGLs.

VME ENERGY FORECAST

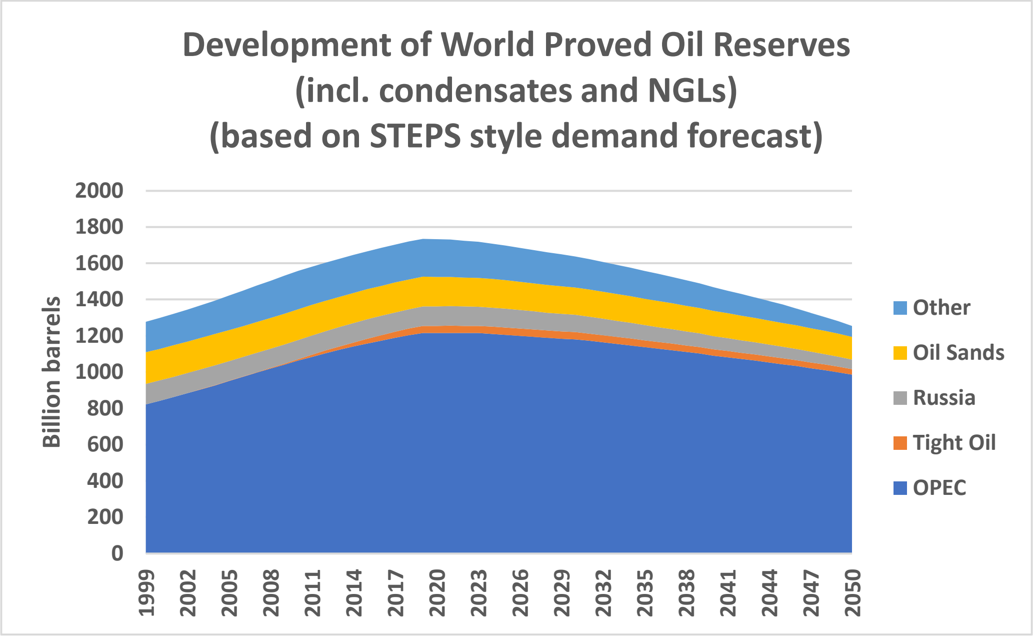
VME Energy Remaining Oil Reserve Forecast

DEVELOPMENT OF PROVED OIL RESERVES (based on STEPS style demand forecast) (Billion barrels) (including condensates and NGLs)						
	OPEC	Tight Oil	Russia	Oil Sands	Other	TOTAL
1999	**821.8**	**0.0**	**112.1**	**175.2**	**168.0**	**1277.1**
New Reserves	344.0	5.5	28.5	5.6	151.1	534.7
Production	125.0	0.5	35.0	11.0	108.5	280.0
2009	**1040.8**	**5.0**	**105.6**	**169.8**	**210.6**	**1531.8**
New Reserves	305.8	64.0	41.6	6.7	111.3	529.4
Production	131.9	29.0	40.0	13.0	113.4	327.3
2019	**1214.7**	**40.0**	**107.2**	**163.5**	**208.4**	**1733.9**
New Reserves	94.1	33.6	27.5	3.0	114.6	272.7
Production	128.1	34.1	39.6	15.0	151.8	368.6
2030	**1180.7**	**39.5**	**95.1**	**151.5**	**171.2**	**1638.0**
New Reserves	30.2	29.0	5.8	1.4	80.9	147.3
Production	120.9	33.0	28.0	14.4	121.4	317.7
2040	**1090.0**	**35.5**	**72.9**	**138.5**	**130.7**	**1467.6**
New Reserves	8.4	22.0	0.2	0.0	25.7	56.3
Production	113.2	27.4	19.6	13.0	95.6	268.8
2050	**985.2**	**30.1**	**53.5**	**125.5**	**60.8**	**1255.1**

The chart (based on BP data) shows how proved oil reserves sharply increased between 1999 and 2019 despite a significant increase in production. Increases in proved reserves stayed ahead of increases in production. This trend is expected to reverse from now onwards, because it is difficult to promote exploration in the context of an uncertain future of the oil industry. In other words, production will exceed reserve additions. By 2050 the proved reserve will be about the same as they were in 1999 even if we assume a STEPS style demand forecast.

VME ENERGY FORECAST

VME Energy Remaining Oil Reserve Forecast



The chart how the level of proved reserves in Non-OPEC countries will sharply reduce compared to an increase in proved reserves by OPEC between 1999 and 2050.

VME ENERGY FORECAST

Forecast of crude oil price – OPEC policies

Based on the above forecast OPEC will have 985.3 billion barrels of oil reserves in 2050. Non-OPEC, other than Russia, will have apart from huge oil sand and shale oil reserves still 60.8 billion barrels left.

Therefore, OPEC will still have very large resources left in 2050, while Non-OPEC will have limited resources, unless major new discoveries are made.

However, OPEC will face in addition to the competition from Non-OPEC sources the competition from green hydrogen.

VME ENERGY FORECAST

Forecast of crude oil price

Currently hydrogen can be produced through electrolysis at a cost of $ 5 per kg in the US. About 50 kg of hydrogen is equivalent to a barrel of oil. In other words, the current cost of hydrogen is $ 250 per barrel of oil equivalent. The VME forecast is provided previously under the discussion of hydrogen and is as follows:

- **2030 - $ 2.40 per kg - $ 120 per BOE**
- **2040 - $ 1.60 per kg - $ 80 per BOE**
- **2050 - $ 1.20 per kg - $ 60 per BOE**
- **2070 - $ 0.92 per kg - $ 46 per BOE**

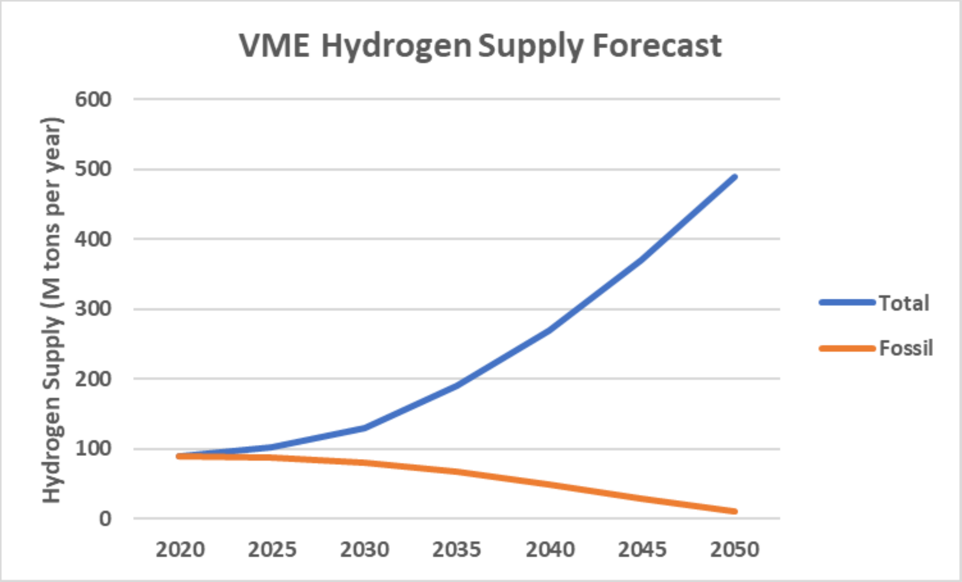
VME ENERGY FORECAST

Forecast of crude oil price

Although Green Hydrogen will become rapidly cheaper, it will take considerable time to build up the electrolyser capacity. The VME hydrogen production forecast is largely based on the IEA forecast. By 2030 the VME forecast is slightly higher than the IEA APS scenario. However, due to significant technological developments a rapid cost decreases, VME is of the view that by 2050 it may approach the IAE NZE scenario.

VME ENERGY FORECAST

VME Hydrogen Supply Forecast



The chart shows the VME forecast, which also shows the decline of the hydrogen production based on fossil fuels which is like the IEA forecast. The difference between the total and the fossil fuel-based hydrogen consists of green and blue hydrogen. It should be noted that 500 Million tons of hydrogen equates to 27.5 million barrels per day equivalent of oil. Therefore, even a much lower level of hydrogen production would have a major impact on the oil price.

VME ENERGY FORECAST

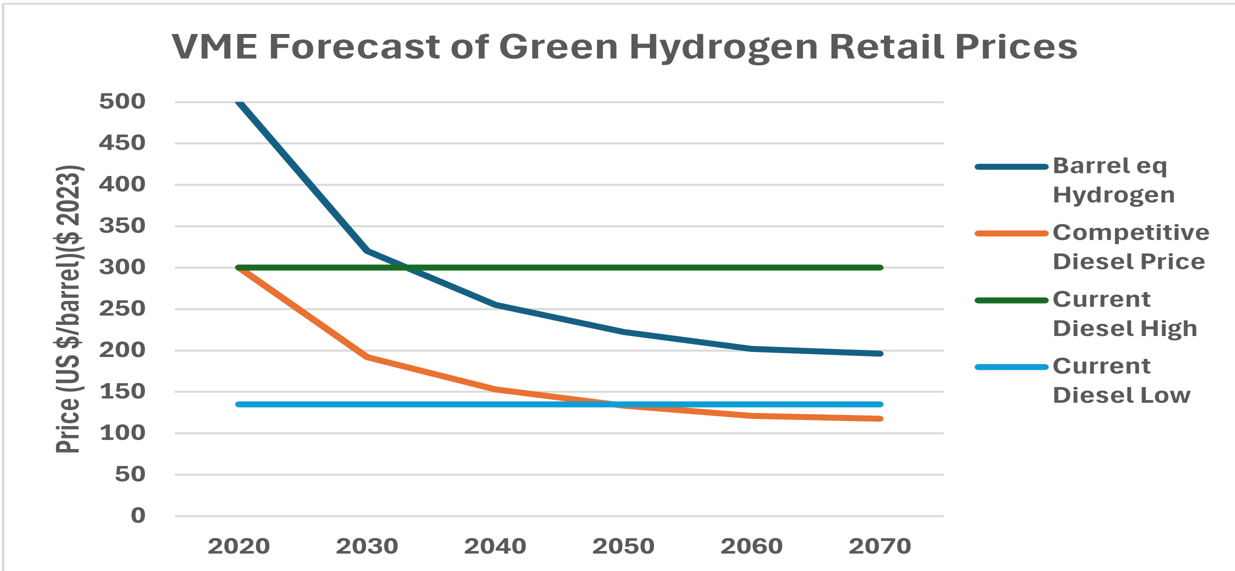
Forecast of crude oil price

In this respect it should be noted that green hydrogen is not competing directly with crude oil, but with the products made of crude oil. In its competition in the transport sector, it should be noted that vehicles based on a fuel cell are almost twice efficient in terms of energy use as those based on an internal combustion engine. It is therefore that about 60% of the hydrogen price per barrel would compete with the diesel price for transport, for instance.

The following chart illustrates the competition between hydrogen and diesel for transport on a retail basis (note: some of the high diesel prices include VAT or other taxes).

VME ENERGY FORECAST

VME Average Oil Price Forecast

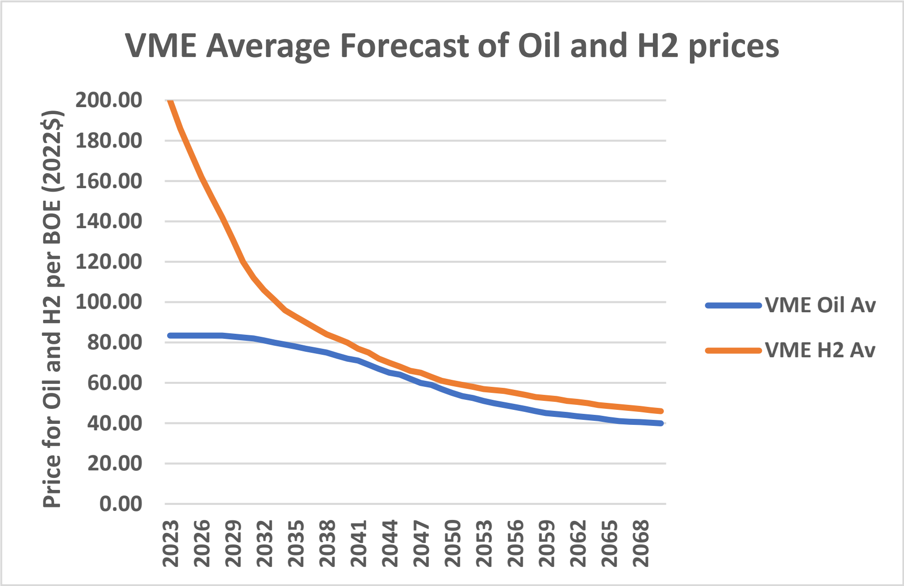


The chart shows that even today at $ 500 per barrel equivalent in the retail market, hydrogen is competing in some high-cost diesel markets since is already being sold commercially (as by the H2 Mobility filling station in Germany).

By 2030 it can be expected that hydrogen will be fully competitive in the European and Japanese-Korean diesel retain markets. By 2040 it will be competitive in the US diesel retail markets and by 2050 even in the markets in the Middle East (assuming non-subsidized prices). These and other hydrogen effects will push the oil price down.

VME ENERGY FORECAST

VME Average Oil Price Forecast



The chart shows how the VME oil price forecast is in part determined by the H2 forecast. The green hydrogen price will start pushing the oil price down from about 2035.

VME ENERGY FORECAST

Low and high forecast of crude oil price

It should be noted that there is a wide range of opinions of the future hydrogen costs. Some experts such as the CRU Group predict that it will be extremely difficult for hydrogen to reach a cost level of $ 2/kg. They expect hydrogen prices to remain high. If also renewable costs remain much higher than anticipated by VME, oil production will continue to play a considerable role and the depleting resources in Non-OPEC countries may permit OPEC to force a continuation of rather high prices. This concept corresponds very much with the STEPS scenario of the IEA.

VME ENERGY FORECAST

Low and high forecast of crude oil price

On the other hand, other experts such as the Rethink Energy Group estimate hydrogen costs by 2050 that are lower than VME.

VME is of the view that rather low prices for hydrogen can be achieved in case of important technical breakthroughs in hydrogen production. A wide variety of breakthroughs could occur, for instance, with respect to:

.. Direct solar to hydrogen

.. Processes based on waste heat

.. Chemical processes, such as based on aluminum and water (an exothermic reaction, not requiring any energy)

VME ENERGY FORECAST

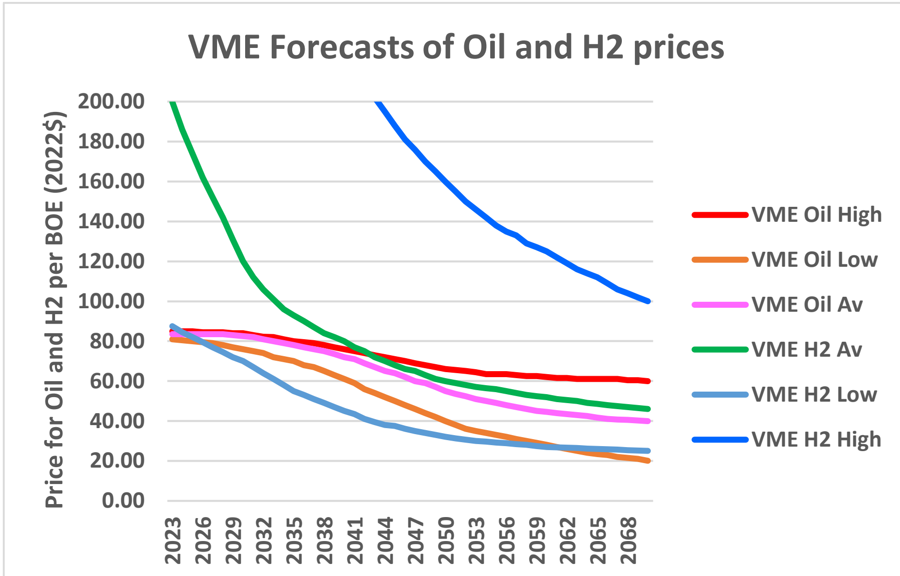
Low and high forecast of crude oil price

The following chart provides the alternative hydrogen forecasts. The high forecast assumes a somewhat higher economic growth and a supply and demand scenario more like the IEA STEPS scenario with initial upward pressure on oil prices. The low forecast assumes a somewhat slower economic growth and sharper decline of oil supply and demand from 2030 onwards.

The high hydrogen price forecast will not have a significant impact on the future oil price. The low hydrogen price forecast will pull down the oil price significantly. It will the assumed that under the low H2 price forecast the differential with crude oil prices will be rather high initially because total hydrogen production will initially be modest.

VME ENERGY FORECAST

VME Low and High Oil Price Forecast

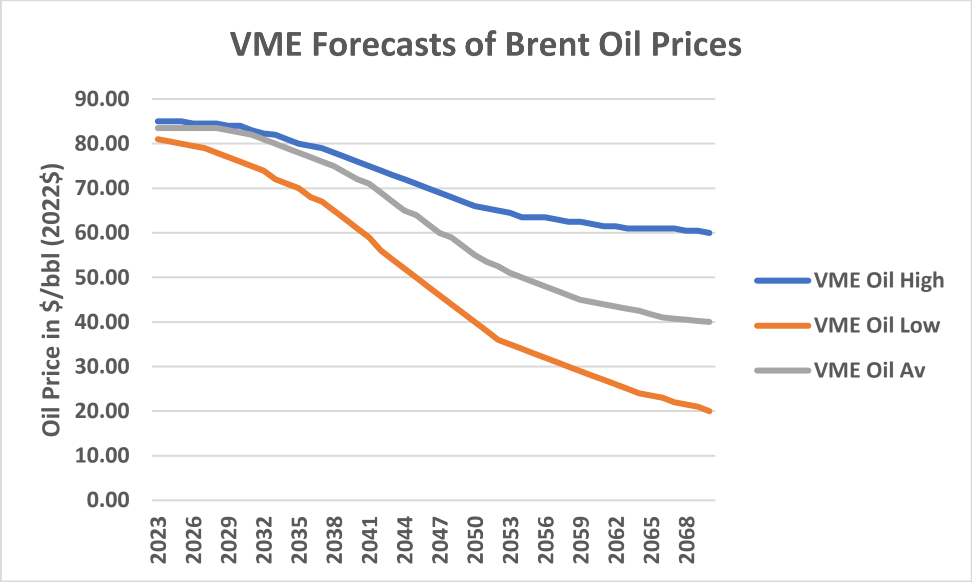


The chart shows how the VME low and average oil price forecasts are determined by the low and average forecasts of the green hydrogen prices.

If green hydrogen prices will stay high the impact will be minimal and the main downward pressure on oil prices will be caused by OPEC dropping oil prices to protect market share as displayed earlier in the liquid supply forecast

VME ENERGY FORECAST

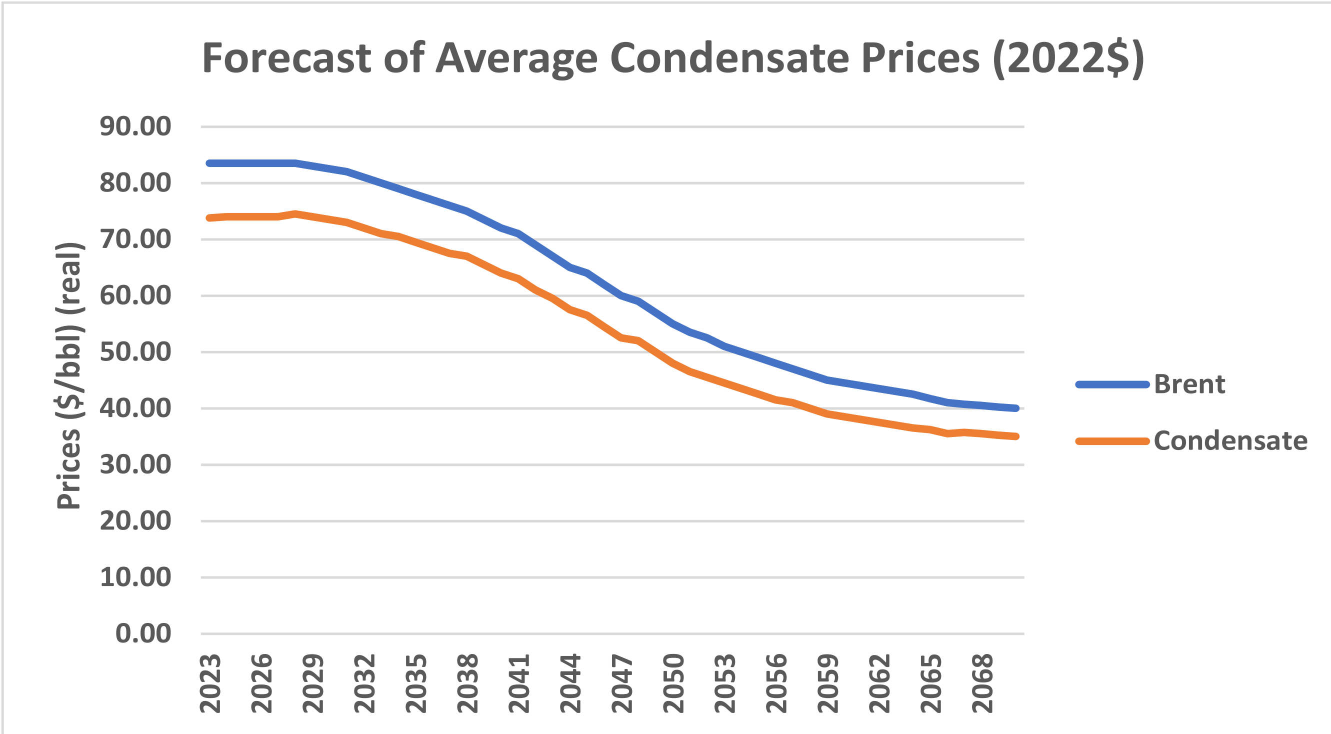
VME Low, Average and High Oil Price Forecast



The chart shows the VME forecasts of oil prices, reaching in 2070 $ 60 per barrel for the high forecast, $ 40 per barrel for the average forecast and $ 20 per barrel for the low forecast.

VME ENERGY FORECAST

VME Condensate Price Forecast



Based on the average forecast for Brent, the condensate forecast is presented in the above chart. It can be estimated that the differential will gradually contract as the price declines, from $ 10 per barrel to $ 5 per barrel, resulting in an average forecast of $ 35 per barrel by 2070 for condensates.

VME ENERGY FORECAST

Forecast of natural gas prices

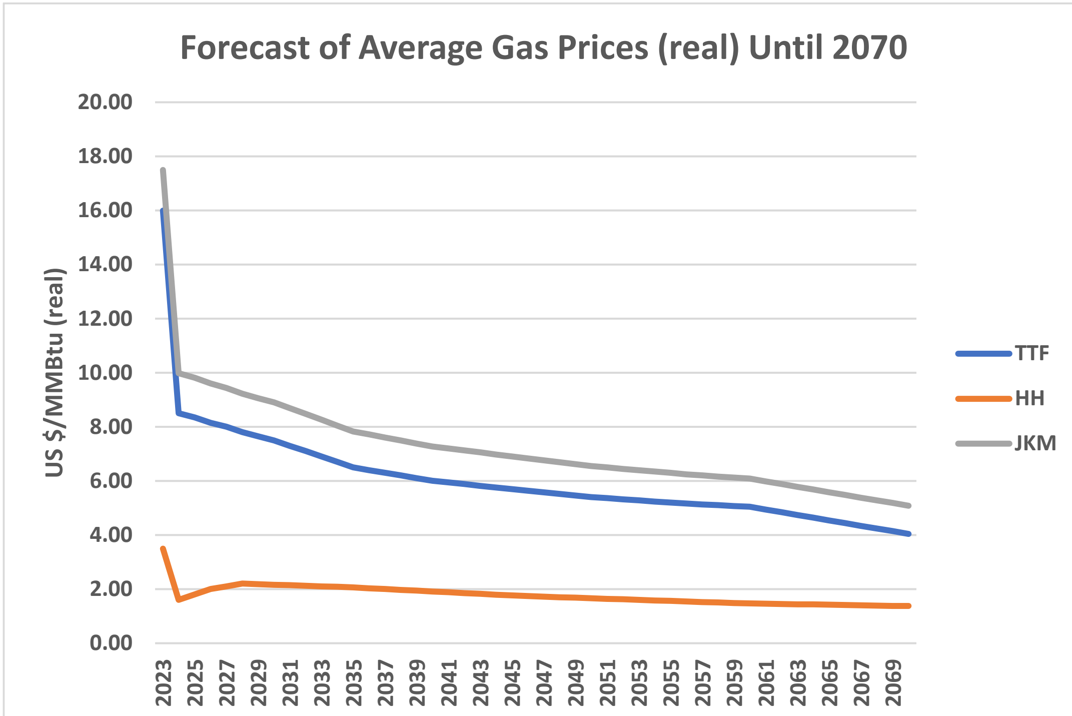
It is forecasted that the regional differences between the various gas price indicators remain. Forecasts are made for Henry Hub (HH), Title Transfer Facility (TTF) and Japan-Korean Marker (JKM).

The HH gas collapsed in early 2024 to its lowest level ever (in real terms). A slight recovery can be expected. However, by 2050 low gas prices will be the norm.

Europe has handled the cutoff from Russian gas supplies remarkably and gas reserves are higher than required at the beginning of 2024 with gas prices returning to pre-crisis levels. JKM will probably trail at about $ 1.50 over TTF.

VME ENERGY FORECAST

VME Natural Gas Price Forecasts



The above chart displays the VME forecast for gas prices for Henry Hub (HH), Title Transfer Facility (TTF) and Japan-Korea Marker (JKM). After 2060 the gas prices can be expected to crash due to very low demand.

VME ENERGY FORECAST

Conclusion on VME Energy Production Forecast

The discussion under “Renewable Energy Development” and “Impacts on the Petroleum Industry” justifies the VME forecast that the future costs of renewables will drop faster than the IEA is predicting and that the process of electrification of energy demand will therefore develop faster.

If is for this reason that the VME Energy Production Forecast seems entirely justified.

VME ENERGY FORECAST

Conclusion on VME Energy Production Forecast

It should be noted that the VME forecasts of energy production would alter very much if due to unforeseen technical developments the costs of hydrogen would drop well below $ 0.50/kg (2020$) at any particular moment. A huge amount of research is ongoing to achieve this.

In this case it can be expected that natural gas will be rapidly replaced by hydrogen to be transported on 100% hydrogen pipeline networks.

Also in this case, it can be expected that the petroleum production will increasingly be supplied with synthetic gasoline, synthetic diesel and synthetic jet fuel.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

Reduction of role of fossil fuels

What is remarkable is that petroleum companies actually do not participate in a major way in the petrochemical industries.

In their Oil 2020 report, the IEA lists the petrochemical projects under construction or planned for development. The total new capacity is estimated to be 38.4 million tons per year.

Of this total the major international petroleum companies represent only 5 million tons or 13%, consisting of plants in the United States and South Korea, while other petroleum companies in China, Russia, Asia and Canada represent 8%.

The petrochemical industries are highly competitive, and it will therefore be difficult for petroleum companies to diversify in a major way into these industries in order to increase their role.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

Reduction of role of fossil fuels

Ownership of New Petrochemical Plants		
	Total	Oil Companies
	k tons/year	k tons/year
United States	9481	4300
China	9200	740
Russia	3720	420
Other	15979	2590
TOTAL	38380	8050

Ownership of new petrochemical plants based on IEA data.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

Reduction of role of fossil fuels

Nevertheless, several oil companies are specifically linking their operations to the petrochemical industries.

For instance:

-- ONGC of India is planning to set up two oil-to-chemical plants,

-- OQ of Oman is considering a petrochemical plant in Duqm which will be fed NGL from central Oman through a 230 km pipeline, and

--Qatar Energy in cooperation with Chevron Phillips has decided to go forward with the Ras Laffan Petrochemical Project in Qatar.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

Increased Role of Rich Gas

The petroleum industry will be increasingly oriented to the production of rich gas, which is gas that contains condensates and large quantities of natural gas liquids (LPG, ethane and pentanes+), assuming that green hydrogen will not yet play a large role in producing feedstock for the petrochemical industries.

On a Mboepd equivalent basis the production of natural gas, NGLs and biogas will increase from 51% to 56% of the total petroleum production. It is likely that OPEC will benefit by significantly increasing its NGL production.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

CO2 emissions

CO2 Emissions Forecast of IEA (Mtons of CO2)				
	2020	2030	2040	2050
STEPS	34779	36211	33861	31979
APS	34779	31511	20539	12399
NZE	34779	22846	5799	0

VME did not make its own CO2 emission forecast. The IEA forecast of CO2 emission is listed in the above table. Since the VME tracks in APS estimate in total energy but provides for a slightly higher renewables component, the VME forecast for 2050 would be slightly under the APS forecast at about 12.4 M tons.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

CO_2 emissions

The VME conclusion that the 2050 level of CO_2 emissions will be about 14 M tons is reached despite the assumptions that:

-- renewable energy will significantly penetrate power production and replace almost all fossil fuels,

-- low-cost green hydrogen will play an important role in replacing oil and gas and replace a significant share of current industrial hydrogen,

-- the petroleum industry will increasingly produce feedstock instead of fossil fuels,

TRANSFORMATION OF THE PETROLEUM INDUSTRY

CO_2 emissions

(continued);

-- road vehicles will largely convert to EV's and hydrogen,

-- natural gas for buildings will reduce,

-- some marine transport will convert to renewable fuels, and

-- a percentage of air transport will be based on hydrogen, biofuels, synfuels and some electricity.

The remaining CO_2 emissions are so large that it is unrealistic to assume that most of it can be offset by carbon capture and storage. This means that if the world wants to achieve the goal of net zero CO_2 emissions by 2050, very strong additional measures will be required, which would have a very large impact on the petroleum industry and are a very significant future risk element.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

CO_2 emissions

At the same time is should be realized that achieving the NetZero objectives is of extreme importance. The typical climate impacts of not achieving these goals are well reported. However, not achieving the goals could also increase the extremely small possibility that global warming may become uncontrollable. For instance, a more rapid than expected melting of the permafrost could release large amounts of additional CO_2 and methane resulting in more rapid temperature increases in turn causing more rapid melting of the Greenland and Antarctic glaciers.

The permafrost is trapping 1700 billion tons of carbon (50 times the current yearly emissions). The melting of all of the world's glaciers would result in a sea level increase of 70 meters.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

CO_2 emission targets set by Companies

It should be noted that a number of large integrated European petroleum companies have now set their own CO_2 emissions targets for 2050.

The results are tabulated by the Transition Pathway Initiative ("TPI"), which advises investors about the progress companies make in accordance with the Paris Agreement.

TPI reports the results based on information by the companies as well as their own adjustments, the main adjustment that TPI makes is including the CO_2 emissions that would be derived from the petroleum products, electricity and renewable energy sold by the companies. Adjustments are made for biofuels and for products sold as feedstock.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

CO_2 emission targets set by Companies

The TPI results are provided as tons of CO_2 emitted per TeraJoule products sold ("carbon intensity").

In 2015 the intensity was typically in the range of 65 to 75 tCO_2/TJ.

Companies can reduce their carbon intensity by:

-- using less fossil fuels in producing the products to be sold,

-- selling more non fossil fuel energy (renewable electricity, green hydrogen, biofuels and green hydrogen based synfuels),

-- increasing natural gas sales versus oil sales,

-- increasing carbon capture and storage, and

-- employing other offset mechanisms (planting trees).

TRANSFORMATION OF THE PETROLEUM INDUSTRY

CO2 emission targets set by Companies

Carbon Intensity by 2050 (tons CO2/TJ)	
BP	53
Paris Pledges	49
Repsol	35
Total	30
ENI	29
Shell	25
2 Degrees	19
Below 2 Degrees	7

The TPI information indicates that some European large oil companies have aggressive carbon intensity targets. Shell would almost achieve the Paris Agreement goal for 2 degrees Celsius of 19 tons CO2/TJ. The latest 2021 Shell Transition Strategy calls for 0 tons/TJ by 2050.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

CO_2 emission targets set by Companies

Separate from the TPI results, there are a number of other petroleum companies that have set net-zero targets of various degrees, such as:

2045 – SoCalGas

2050 – Suncor, Petronas, Occidental Petroleum, OMV, Equinor,

TRANSFORMATION OF THE PETROLEUM INDUSTRY

Structure of the Petroleum Industry

The movement from current price levels to $ 60/bbl, $ 50/bbl or even $ 40/bbl under the VME Low Oil Price forecast will have a deep impact on the structure of the petroleum industry.

The profitability of oil field development, and as a result exploration, will be affected. The profitability can be measured in different ways. In the following chart it is measured as the PIR10, which stands for the Profit to Investment Ratio @ 10%. This is the ratio of the Net Present Value @ 10% divided by the total capital investment over the life of the field also discounted at 10%.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

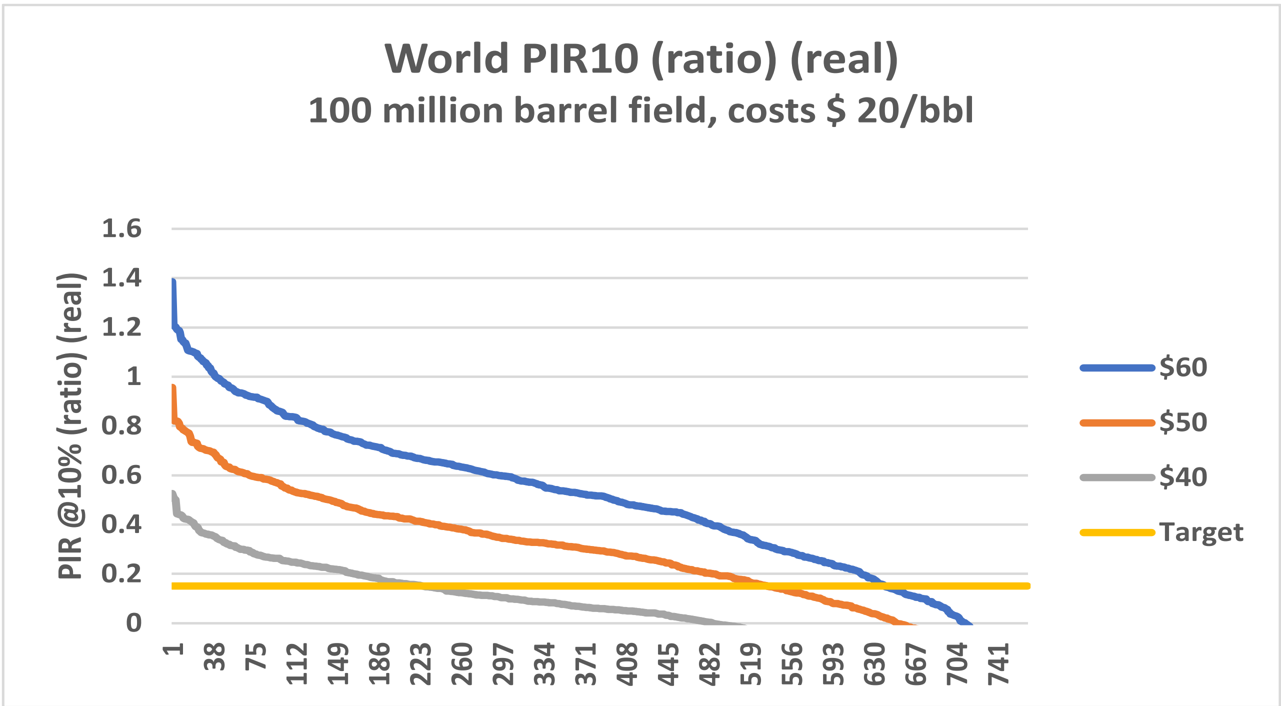
Structure of the Petroleum Industry

The profitability of oil field development is very much impacted by the fiscal terms. Van Meurs Energy has developed a world data base of more than 800 fiscal systems from all countries that have petroleum leases, licenses or contracts with the petroleum industry (This data base is being expanded continuously).

Therefore, the profitability can be measured on a worldwide basis, by ranking the fiscal systems from the most profitable to the least profitable. The following chart assumes that oil companies would have a minimum target PIR10 of 0.15. Of course, at a PR10 or less than 0, it means that the field makes less than 10% IRR.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

Structure of the Petroleum Industry



The chart illustrates how of 768 fiscal systems, assuming a minimum PIR10 of 0.15, a 100 million barrel fields costing $ 20/bbl would be economic in 642 systems at $ 60/bbl, 535 systems at $ 50/bbl and only 227 systems at $ 40/bbl. It should be noted that on a long-term basis also costs can be expected to be lower and therefore the overall effect is less dramatic than indicated in the chart

TRANSFORMATION OF THE PETROLEUM INDUSTRY

Structure of the Petroleum Industry

The chart shows how for a 100 million barrel field at $ 20/bbl, 642 fiscal systems would be economic at $ 60/bbl. (The systems that are uneconomic are typically in countries with lower costs and would therefore be economic at such lower costs.) At $ 50/bbl in total 535 fiscal systems are economic and at $ 40/bbl only 227 systems.

This indicates that based on our Low Oil Price forecast oil field development and in particular exploration, would be negatively impacted, in particular once prices move to the $ 40/bbl level.

The actual result would be less severe than indicated in the chart, because with lower prices, usually costs will also decline and in the long term lower costs can be expected as a result of technological improvements.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

Structure of the Petroleum Industry

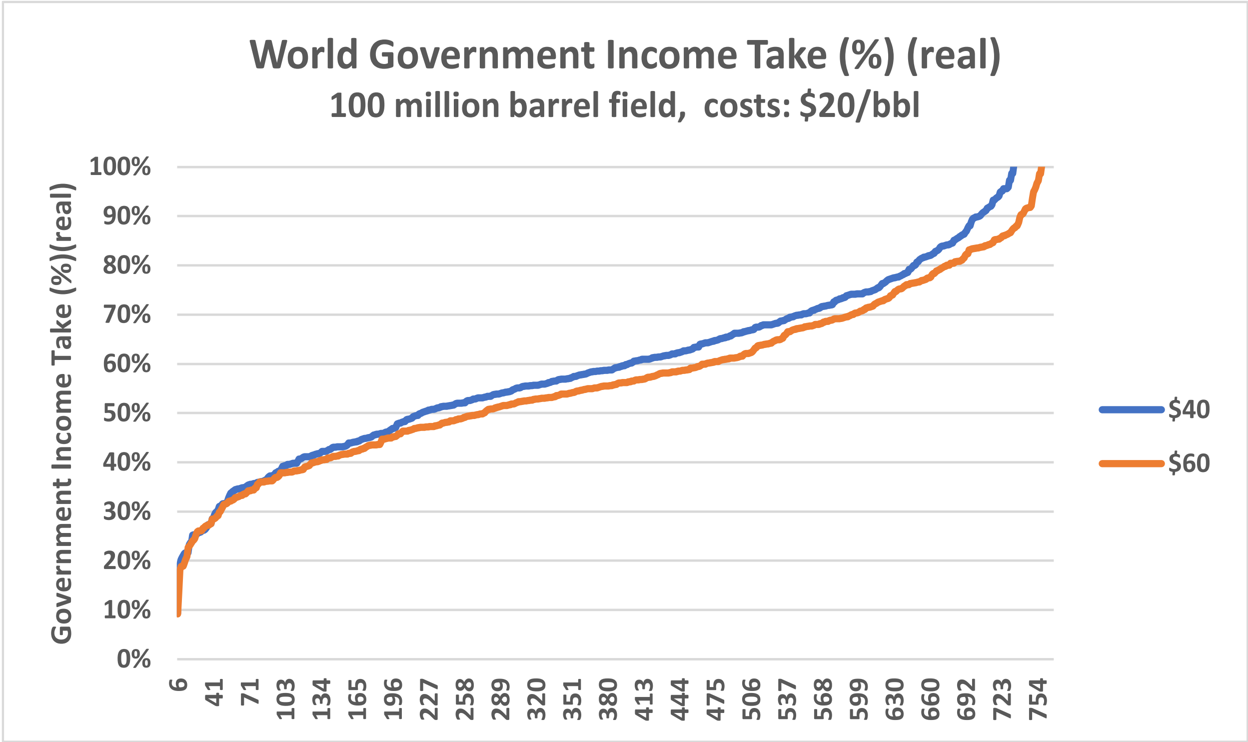
It should be noted that the negative impact on world development and exploration, is in part the result of the fact that fiscal systems are not structured to deal with this situation.

The following chart shows the Undiscounted Government Income Take ("GIT0") on the same worldwide basis.

(For a detailed explanation of government take, see the start of the section on "Fiscal Systems").

TRANSFORMATION OF THE PETROLEUM INDUSTRY

Structure of the Petroleum Industry



The chart illustrates how the GIT0 is higher under $ 40/bbl than under $ 60/bbl. This means that governments actually harm the ability of companies to develop and explore for oil if oil prices decline.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

Structure of the Petroleum Industry

The chart shows how the GIT0 at $ 40/bbl is actually higher than under $ 60/bbl. This means the fiscal structure of most governments actually harms the ability of petroleum companies to explore and develop under lower prices. Such a fiscal system is called a price regressive system.

Therefore, it can be recommended that those countries that are interested in maintaining exploration and development under low oil prices change their fiscal terms to a price progressive system under low oil prices. This matter will be discussed in more detail later in the presentation.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

Structure of the Petroleum Industry

As discussed earlier, hydrogen can be transported through the same gas pipeline and distribution network as natural gas, even in combination with natural gas.

The combined production of natural gas and hydrogen is anticipated to increase over the next 30 years.

It can therefore be expected that the gas pipeline and distribution network will expand.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

Structure of the Petroleum Industry - Summary

Based on the forecasts in this presentation, the structure of the petroleum industry can be expected to change rather significantly over the next 30 years:

-- petroleum exploration will decline significantly,

-- upstream oil and dry gas development will decline,

-- upstream rich gas development will expand significantly,

-- oil refining will decline,

-- gas processing will expand significantly,

-- oil and product pipeline transportation will decline, and

-- gas pipeline transportation and distribution will expand.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

ROE of the Petroleum Industry

Based on Bloomberg data the Rate of Return on Equity of the petroleum industry as gradually declined since 2005.

In 2005 it was typically a high 25%, by 2015 this was down to 8%, by 2019 it was back up slightly to 10%.

This year a very low ROE can be expected, probably at best 4%.

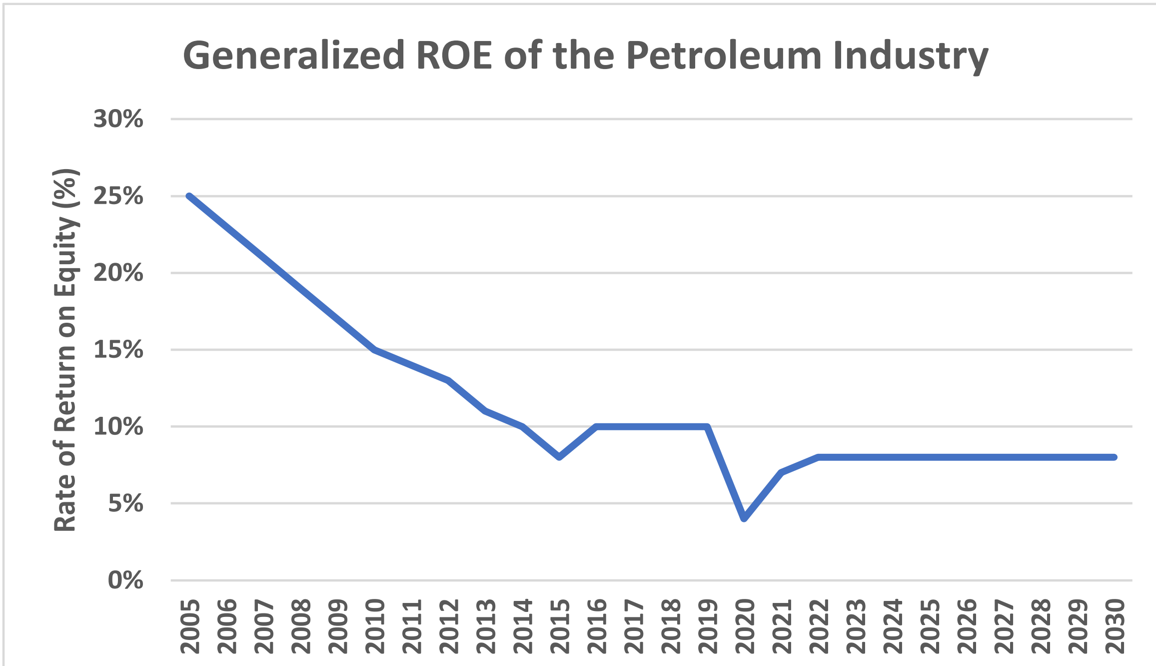
During the coming decade it is difficult to see a high ROE.

Contrary to the past, the petroleum industry as a whole is now under increased competitive pressure from renewables with low ROE's and easy entrance for non-oil companies.

The reduction of petroleum exploration reduces the competitive justification for high ROE's. It is therefore difficult to see how ROE's will go well over 8% in the next decade. This is a ROE similar to the renewable industries.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

ROE of the Petroleum Industry



The chart illustrates how the ROE can be expected to be about 8% during the next decade, similar to the renewable industries.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

Conclusion: Four Challenges

It can be concluded that the four challenges facing the petroleum industry will have a very significant impact as follows:

-- renewable energy will increasingly result in the production of lower cost electricity and heat,

-- lower costs electricity storage will create a power industry that will no longer need fossil fuels,

-- hydrogen may become sufficiently low in costs to have a significant impact on petroleum consumption, and

-- climate change may create a world which would rapidly move away from fossil fuels.

TRANSFORMATION OF THE PETROLEUM INDUSTRY

Conclusion

The risk profile of the petroleum industry will change dramatically during the next 30 years. Ten years ago, the petroleum industry was unique due to the large role of exploration risk. From now on that risk will be less important as less exploration will be done.

However, in particular two very significant business risks now affect the industry. The introduction of tougher climate policies could greatly negatively affect the industry. In the long term a low hydrogen price as a result of R&D and lower renewable energy costs would have massive negative impacts.

In the following "Energy Transition" section it will be evaluated how the energy industries respond to the new framework and how governments need to change.

ENERGY TRANSITION-SUPPLY

Scope Approach

In designing energy transition strategies, the "Scope" approach could be used in order to relate the strategies to the level of control a company has over its actions. In this case:

-- Scope 1 – relates to the green house gas emissions that the company creates directly, for instance through its equipment of vehicles.

-- Scope 2 - relates to indirect emissions related to the energy purchases it makes, for instance purchasing electricity.

-- Scope 3 – relates to the indirect emissions created by the products or services it purchases for its operations, and the emissions caused by its products when customers use them.

ENERGY TRANSITION-SUPPLY

Structure of the Petroleum Industry

As discussed earlier, hydrogen can be transported through the same gas pipeline and distribution network as natural gas, even in combination with natural gas.

The combined production of natural gas and hydrogen is anticipated to increase over the next 30 years.

It can therefore be expected that the gas pipeline and distribution network will expand.

ENERGY TRANSITION-SUPPLY

Structure of the Petroleum Industry - Summary

Based on the forecasts in this presentation, the structure of the petroleum industry can be expected to change rather significantly over the next 30 years:

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-- upstream oil and dry gas development will decline,

-- upstream rich gas development will expand significantly,

-- oil refining will decline,

-- gas processing will expand,

-- oil and product pipeline transportation will decline, and

-- gas pipeline transportation and distribution will expand.

ENERGY TRANSITION-SUPPLY

Companies involved

The following pattern currently exist with respect to companies involved in energy transition from the point of view of supplies:

-- petroleum companies with a strong interest in diversifying, such as Shell and Total,

-- petroleum companies with a low or no interest in diversifying, such as Chevron and Rosneft,

-- power companies, most of which are interested in adding renewable energy to their portfolios,

-- companies investing in wind power,

-- companies investing in solar power,and

-- independent hydrogen producers

Each of these groups will be discussed.

ENERGY TRANSITION-SUPPLY

Petroleum companies which are diversifying

The petroleum companies that have a strong interest in diversifying have rather different strategies in terms of the type of renewable energy they are pursuing.

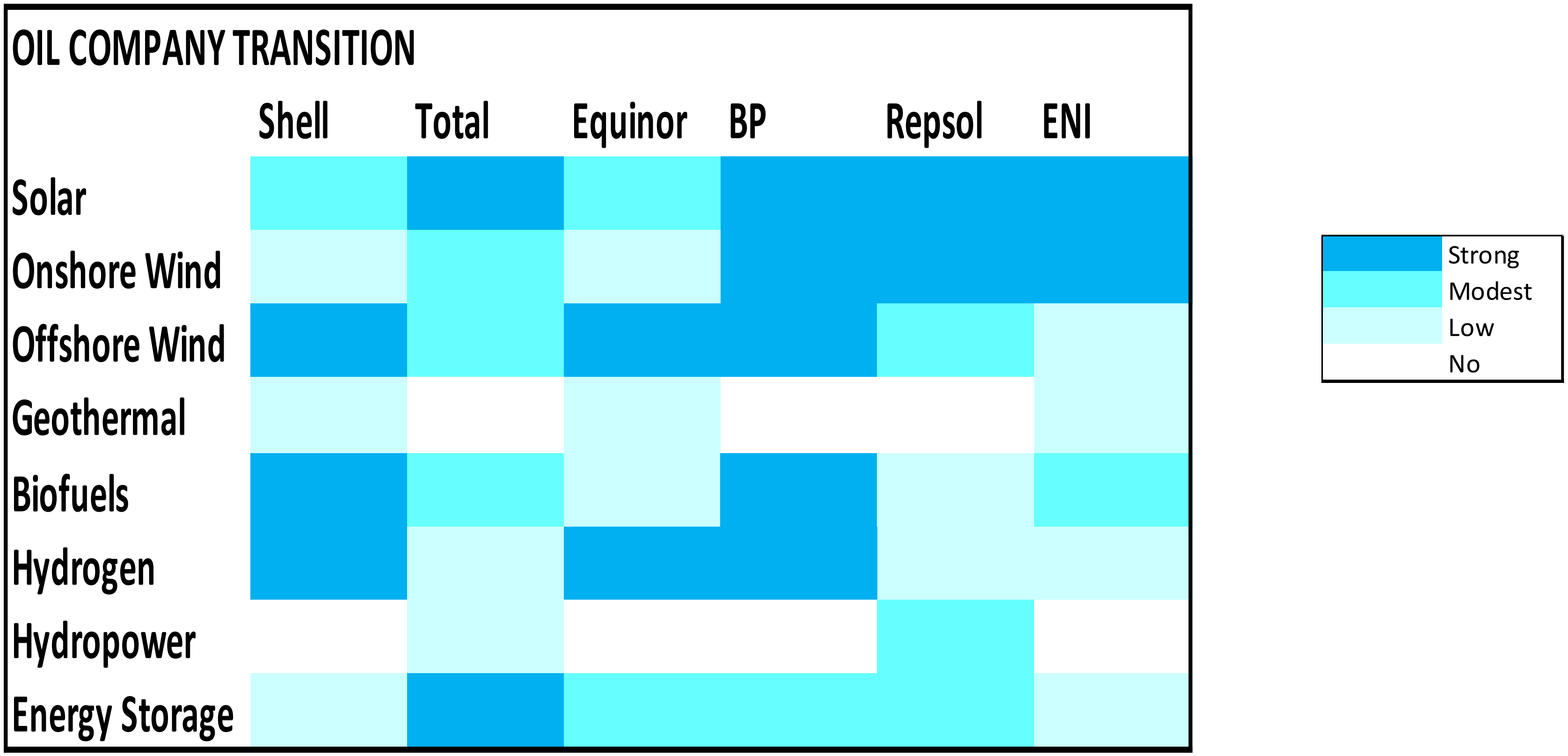
The type of renewables they are diversifying to and the research and development they are doing are different.

The following slide illustrates these differences. The chart lists strong, average, low or no interest. This is the interest within each company, not on a global basis.

Thereafter a brief summary will be provided for each of the petroleum companies.

ENERGY TRANSITION-SUPPLY

Petroleum companies which are diversifying



The chart illustrates that in general petroleum companies are not interested or have a low interest in geothermal power and hydropower, while all of them have a modest or strong interest in solar energy, while wind, biofuels and hydrogen are also major focus areas. "Strong", "modest", "low" and "no" means relative emphasis within the company.

ENERGY TRANSITION-SUPPLY

Petroleum companies which are diversifying

Shell:

-- investing heavily in offshore wind such as the Borssele 3&4 project (731 MW) (the Netherlands), offered a record low price of 5.8 cents/kWh for an 804 MW windfarm offshore Massachusetts.

-- has several onshore wind farms in the USA,

-- has a large number of hydrogen stations for road vehicles in Germany and other countries

-- produces ethanol through Raizen in Brazil,

-- bought 44% of the shares of Silicon Ranch with 880 MW solar,

-- investing in the Rotterdam green hydrogen project based on wind and plans an 800 million kg/year hydrogen project by 2040,

-- Shell has joined in 2023 the Vindoe consortium to construct the first Energy Island off Denmark in the North Sea.

ENERGY TRANSITION-SUPPLY

Petroleum companies which are diversifying

Total:

-- Changed its name to TotalEnergies. It plans for 2050 are that of its sales 25% is from oil and gas, 50% electricity and renewables and 25% from hydrogen and renewable biofuels.

-- will install 20,000 EV charging points in the Netherlands,

-- acquired a stake in the 96 MW Erebus floating wind project,

-- is investing in an 800 MW solar project in Qatar,

-- will install 1000 MW as part of four energy projects in Iraq,

-- has a 0.5 million ton biorefinery in Southern France,

-- is participating in a green methanol project in Leuna, Germany,

-- is constructing a 1500 hydropower project in Mozambique.

-- Is offsetting its CO2 emissions with a large reforestation program in the US.

ENERGY TRANSITION-SUPPLY

Petroleum companies which are diversifying

Equinor:

-- aims to be NetZero by 2050

-- is building the large Hywind floating wind farm offshore Scotland and is participating in a large number of offshore wind projects,

-- will supply "blue" hydrogen to the Magnum powerplant in the Netherlands,

-- is considering a geothermal investment in Iceland,

-- is co-investor in the 162 MW Apodi solar plant in Brazil, with more solar investments planned,

-- has invested in a Swedish biofuel plant using wood pellets, and

-- has invested in the 1 MW Batwind storage project in Scotland.

ENERGY TRANSITION-SUPPLY

Petroleum companies which are diversifying

BP:

-- is 50% shareholder of LightsourceBP, one of the largest solar companies with a capacity goal of 10,000 MW by 2023,

-- is developing 5.9 GW of offshore wind off the East Coast of Scotland and in the Irish Sea with EnBW

-- has been awarded sites for 4 GW offshore wind generation in Germany

-- is carrying out study for a green hydrogen plant in Australia, and intends to construct green hydrogen plants in Oman and Mauritania

-- operates 9 onshore windfarms with a total capacity of 1,679 MW in the US,

-- has a feedstock agreement with a 36,000 bopd biodiesel plant in Oregon,

-- has bought out Bunge Bioenergia of Brazil, producing 26,000 bopd of ethanol and 1200GW of biomass electricity per year, from sugarcane, and

-- Intends to invest in a 100 MW green hydrogen project in Australia for exports.

ENERGY TRANSITION-SUPPLY

Petroleum companies which are diversifying

Repsol:

-- is developing 3 solar projects in Spain; in total 595 MW,

-- is developing 26 onshore wind projects in Spain with a total capacity of 860 MW,

-- they operate 12 hydropower projects in Spain,

-- are developing a 25 MW offshore floating wind farm off Portugal,

-- is carrying out research for a hydrogen plant based on solar, and

-- is investing in Ampere Energy a battery storage start up,

-- has signed an agreement to provide Ryanair will 52 million gallons of SAF between 2025 and 2030.

ENERGY TRANSITION-SUPPLY

Petroleum companies which are diversifying

ENI:

-- is building a 10 MW solar facility in Pakistan, a 34 MW project in Australia, a 5 MW plant in Tunisia, as well as a plant in Algeria,

-- hopes to achieve in total 3,000 MW capacity in various countries by 2023,

-- is building a 48 MW onshore wind farm in Kazakhstan,

-- is successfully operating an inertial sea wave energy converter offshore Ravenna, Italy, and

-- has a pilot plant in Ragusa to convert CO2 from petroleum operations with sun light in a bioreactor with algae to produce bio-diesel.

ENERGY TRANSITION-SUPPLY

Pipeline companies

Companies do not have to be integrated petroleum companies to diversify. The Canadian oil and gas pipeline company Enbridge has massively invested in renewables as follows:

-- 21 wind farms of 3,912 MW capacity, of which 4 are offshore wind farms in Europe and the others are onshore farms in North America

-- 4 solar projects of 152 MW, with remarkably 3 in Ontario,

-- 5 waste heat recovery facilities from pipeline compressor stations producing power,

-- a geothermal project of 22 MW in Oregon, and

-- a 2 MW hydropower project in Ontario

ENERGY TRANSITION-SUPPLY

Petroleum companies which are not diversifying

There are various petroleum companies with only a limited interest or no interest in diversifying, such as:

-- Occidental, but with a program to create 70 DAC projects worldwide by 2035,

-- ExxonMobil, with only small wind and solar projects, but with a strong emphasis on algae research to produce biofuels,

-- Chevron, with small solar, wind and biofuel projects and a 49 MW geothermal project in California and has started a project to produce 2.2 tons of green hydrogen per day in California. Chevron received a greenhouse gas assessment permit from Australia to look for a CCS hub.

ENERGY TRANSITION-SUPPLY

Petroleum companies which are not diversifying

-- Petrobras, with a large ethanol operations,

-- Lukoil, with 298 MW of hydropower in Russia and some small wind and solar projects in Romania, and

-- Rosneft.

ENERGY TRANSITION-SUPPLY

Petroleum companies becoming chemical companies

OMV, an Austrian company, has decided to become a chemical company.

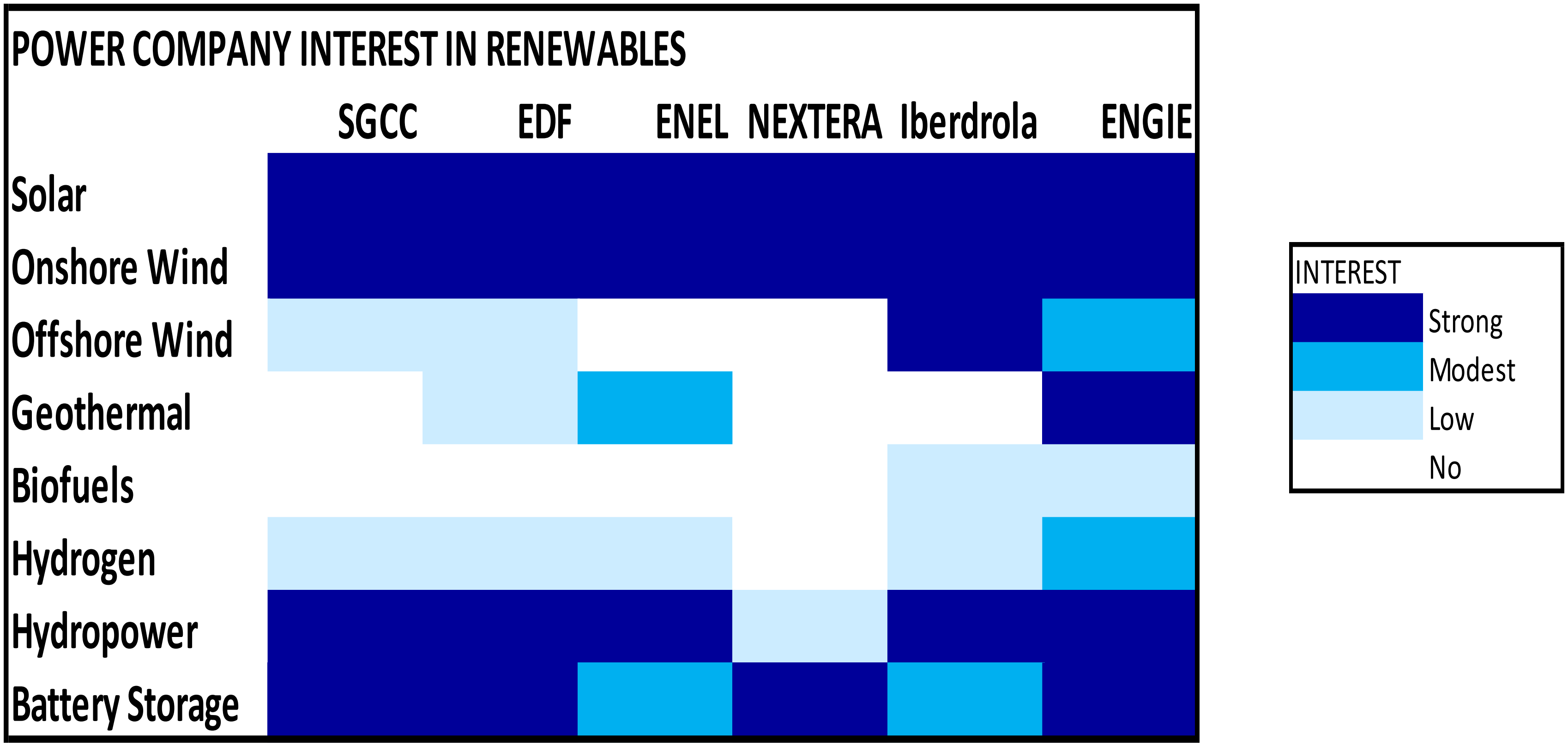
Energy fuels will decline, but OMV estimates that certain plastic products will expand by 4.7% per year until 2030.

The intend to reduce the role of oil and gas in the operating profit to 30% by 2030 from 44% today and increase the role of chemicals to 50% from 29% today.

They will invest together with InterZero in the largest sorting plant for chemical recycling in Europe.

ENERGY TRANSITION-SUPPLY

Power Companies



The chart illustrates that in general power companies have a low interest in biofuels and a limited interest in hydrogen production. Power companies are strongly interested in solar and onshore wind and most are interested in hydropower (in particular pumped power) and battery storage.

ENERGY TRANSITION-SUPPLY

Power Companies

State Grid Corporation of China (SGCC):

-- has installed 13,440 MW of onshore wind power (2017 data),

-- has installed 48,770 MW of solar PV (2017 data),

-- has 8,400 MW pumped storage and considerable other hydropower (2017 data),

-- has a small offshore wind project,

-- has a storage project of 36 MWh based on BYD lithium iron phosphate batteries, combined with 100 MW of wind and 40 MW of solar, and

-- is designing a hydrogen storage site.

ENERGY TRANSITION-SUPPLY

Power Companies

EDF of France:

-- has a company called EDF Renewables with over 10,000 MW of solar, onshore wind and storage capacity in North America,

-- operates 1070 MW of 2 hydropower projects in Laos,

-- has geothermal projects in Guadeloupe and France,

-- created a company Hynamics for the production and distribution of hydrogen and owns an electrolyser company,

-- is planning a 1300 MW wind project offshore Ireland,

-- is the largest hydropower company in Europe with 20 GW of hydropower in France and further projects in other countries, and

-- has established a subsidiary for its Nuward Small Modular Reactor.

ENERGY TRANSITION-SUPPLY

Power Companies

ENEL of Italy:

-- ENEL Green Power produces over 100 TWh of renewable energy from 43,000 MW of managed installed capacity in 29 countries in five continents consisting mainly of onshore wind and solar PV,

-- is investing 160 billion euros up to 2030 in a clean energy drive,

-- is not involved in offshore wind but is constructing 200 MW of geothermal in Italy.

-- is constructing 1600 MW battery storage in Italy

-- has produced the first transportable microgrid 100% renewable energy in Chile consisting of 125 kW solar PV, 450 kW hydrogen storage and 132 kW of lithium-ion storage,

-- is finalizing a 3 GW solar panel factory in Oklahoma, and

-- is committing to become a carbon free company by 2050.

ENERGY TRANSITION-SUPPLY

Power Companies

NEXTERA of the US:

-- NextEra is the largest renewable energy firm in the US, with a "pipeline" of 250 GW in terms of renewable and storage projects.

-- of its total power capacity of 28,400 MW in the USA, has 3,100 MW of solar PV and 16,000 MW of onshore wind,

-- not involved in offshore wind,

-- has 140 MW of battery storage,

-- has no hydropower, except considering a pumped storage projects in California, and

-- is not involved outside the USA.

ENERGY TRANSITION-SUPPLY

Power Companies

IBERDROLA of Spain:

-- has 53,400 MW of installed capacity worldwide of which 70% is renewable energy,

-- participates actively in offshore wind, is participant in the 3,100 MW East Anglia offshore project,

-- has large onshore wind projects in Latin America,

-- is constructing an 1158 MW hydropower project in Portugal,

-- is constructing a large 590 MW solar project in Spain,

-- is constructing an algae biomass plant in Mexico,

-- is constructing a 3MWh battery storage project in Spain, and

-- is investing in the 476 MW Baltic Eagle wind farm off Germany.

ENERGY TRANSITION-SUPPLY

Power Companies

ENGIE of France,

-- has 103,000 MW installed power capacity of which 21,500 MW is renewable energy and 20,000 MW of hydropower.

-- has onshore wind generation in a large number of countries,

-- has a floating wind farm of 25 MW offshore Portugal,

-- provides 100 GWh of geothermal heat in the Paris area,

-- has a 4 MW/16MWh battery storage project in Colorado,

-- will in 2022 supply Heathrow with biomethane,

-- has a combined solar/storage project in Corsica, and

-- has applied for a 380 MW Battery Energy Storage System (BESS) in Belgium.

ENERGY TRANSITION-SUPPLY

Wind Companies

It is relatively easy to enter the wind energy market, since there are highly organized wind turbine suppliers. There are already more than 2000 owners of wind farms in the world. The largest are:

-- Orsted – 25,343 MW,

-- Scotish & Southern – 15,754 MW,

-- Copenhagen Infrastructure Partners (“CIP”) – 14,280 MW,

-- Vattenfall – 11,176 MW,

-- China Datang Corp – 8, 966 MW and a variety of other large Chinese wind farm owners,

-- Acciona Energia – 8,095 MW, and

-- Scotish Power – 5,982 MW.

ENERGY TRANSITION-SUPPLY

Solar Companies

It is very easy to enter the solar energy market.

In fact, many countries now offer feed-in tariffs for homeowners that want to deliver solar energy to the grid. India does the same to assist farmers.

There are already thousands of small solar companies with their own solar farms.

However, private solar producers do not need to be small. An example is ACWA who offered the lowest solar price in the latest auction in Dubai of 1.6953 cents/kWh for a 900 MW project.

ENERGY TRANSITION-SUPPLY

Independent Hydrogen Producers

Companies that have been traditionally strong in the production of industrial gases are now moving into hydrogen production.

Examples of such companies are:

-- Linde, the largest industrial gas company in the world, founded by Carl von Linde in 1879 and now headquartered in Dublin, Ireland, and has 75,000 employees.

-- Air Products and Chemicals, located in Pennsylvania selling chemicals and industrial gases,

-- Ballard Power Systems, in Canada, largely focused on PEM hydrogen fuel cells,

-- Ceres Power, promoter of SteelCell technology, and

-- Air Liquide, of France, specialized in industrial gases

ENERGY TRANSITION-SUPPLY

The Role of the Petroleum Industry in Energy Transition

Based on the above analysis it is now possible to obtain an idea about the role of the petroleum industry in the energy transition.

Onshore Wind and Solar PV

It is clear that the onshore wind and solar PV market is already occupied by the large power companies and wide variety of wind and solar farm owners. In fact, each of the 6 reviewed large power companies already produces more onshore wind and solar than the 6 reviewed petroleum companies combined.

It will be very difficult for the petroleum industry to enter these markets on an operational basis, other than occasionally buying a share in a successful independent wind or solar operator; as Shell did with Silicon Ranch and BP with Lightsource BP.

ENERGY TRANSITION-SUPPLY

The Role of the Petroleum Industry in Energy Transition

It can therefore be predicted that petroleum companies will only be able to obtain a small share of the onshore wind and solar PV markets, probably less than 10%.

Offshore Wind

Petroleum companies are better positioned to capture a share of the offshore wind market. In fact, as was demonstrated many power companies are not interested in this market and small operators cannot enter. With the knowledge of offshore technology, petroleum companies have a competitive advantage. The efforts of Shell, Equinor, Total and Repsol to play a significant role in offshore wind may therefore be successful. However, there will be competition with the current large independent offshore wind providers (Orsted, CIP, Vattenfall,etc).

ENERGY TRANSITION-SUPPLY

The Role of the Petroleum Industry in Energy Transition

Geothermal

Power companies and independents have already largely cornered this market and petroleum companies do not appear particularly interested.

Biofuels

Petroleum companies are well positioned to capture a significant share of the biofuels market. Supplying biofuels as part of regular petroleum product distribution is a logical business. In particular advanced biofuels could play a more important role, such as through large scale algae production, as is promoted by ExxonMobil. Power companies are not interested in this market.

ENERGY TRANSITION-SUPPLY

The Role of the Petroleum Industry in Energy Transition

Green Hydrogen

If the cost of producing green hydrogen comes down as predicted in this presentation, the integrated green hydrogen business becomes the logical "home" for the petroleum companies. Also, because the petroleum industry will be able to create a strong position in blue hydrogen. The integrated green hydrogen business would consist of producing hydrogen from wind and solar, distributing the hydrogen through pipeline and distribution systems to power plants, industries and homes and setting up the hydrogen distribution stations for road vehicles and marine vessels. The business will look very much like the integrated petroleum business with upstream, midstream and downstream. However, strong competition from independent hydrogen producers can be expected.

ENERGY TRANSITION-SUPPLY

The Role of the Petroleum Industry in Energy Transition

Hydropower

The hydropower market is very well controlled by the current large and small power producers and is well integrated with the business of producing and selling electricity. It is therefore, that the petroleum industry will not get a significant share of this market. Petroleum companies are not interested in this market.

Utility Scale Battery Storage

Power companies and independents, such as Tesla, are more interested in this market than most petroleum companies and are often better positioned to capture this market, when integrated with battery production. Petroleum companies may gain a small share of this market where it integrates well with the future petroleum and renewable operations.

ENERGY TRANSITION-SUPPLY

The Role of the Petroleum Industry in Energy Transition

<u>Conclusion</u>

It can be concluded that the large power companies and large petroleum companies, as well as smaller wind and solar companies will overlap in producing renewable energy, with different roles being played by the various participants.

Power companies will concentrate on onshore wind, solar, hydropower and battery storage.

Petroleum companies will concentrate on offshore wind, biofuels and hydrogen production.

Smaller wind and solar companies will focus on onshore wind and solar. Independent hydrogen producers will play an important role.

In total it will be a very competitive environment

ENERGY TRANSITION-DEMAND

The Role of Large Consumers

Some of the large consumers of energy are playing a vital role in energy transition. The following companies will be reviewed:

-- Amazon

-- Microsoft

-- IKEA

-- Walmart

-- Nvidia

-- Apple

ENERGY TRANSITION-DEMAND

The Role of Large Consumers

Amazon:

-- has set the goal of being carbon neutral by 2040

-- used 100% renewable power in its operations in 2023, 7 years ahead of schedule, equal to 28GW based on PPAs investing in the purchase of solar and wind in over 500 projects in 27 countries.

-- co-founded the $ 2 billion Climate Pledge Fund

-- will have 100,000 electric delivery vans on the roads by 2030

-- will improve energy efficiency in the thousands of facilities

-- has a spere style building in the Seattle campus with more than 40,000 plants from could forests of 30 countries.

-- hired 18,000 refugees in the US.

ENERGY TRANSITION-DEMAND

The Role of Large Consumers

Microsoft:

-- Has set the goal of being carbon neutral by 2030, largely by entering into carbon removal credits.

-- Intends to be carbon neutral on a Scope 3 basis.

-- Did one of the largest carbon credit deals by purchasing 2.76 million credits from the BECCS project of the Oersted Kalundbord Hub in Denmark.

-- Finances the one-billion dollar Climate Innovation Fund.

-- Invested in the Climeworks Direct Air Capture and Heirloom.

-- Has contracted 19.8 GW of renewable energy assets

-- Has replenished since 2020 61.5 million m3 of water.

ENERGY TRANSITION-DEMAND

The Role of Large Consumers

IKEA:

-- Has set the goal of being carbon neutral by 2050, without carbon offsets.

-- Has the goal of a reduction of 50% of GHG by 2030.

-- Has achieved 100% renewable energy purchase in 25 of its 64 markets.

-- Is removing and storing carbon from the atmosphere through forestry, agriculture and its products.

-- Is going beyond IKEA to help reduce emissions of its suppliers and customers.

-- It should be noted that there was some criticism of NGOs about using natural forest in Romania and not complying with regulations in Brazil.

ENERGY TRANSITION-DEMAND

The Role of Large Consumers

Walmart:

-- Has set the goal of being carbon neutral by 2040, including electrification of all its vehicles including long haul trucks.

-- Is targeting 100% renewable electricity purchases by 2035.

-- Has reduced CO2 emissions by suppliers by 750 million tons since 2017.

-- Plans to retore and protect 50 million acres of land and one million square miles of ocean by 2030

-- In 2022 in total 63% of the global private brands packaging was recyclable, reuseable or industrially compostable.

ENERGY TRANSITION-DEMAND

The Role of Large Consumers

Nvidia:

-- By 2025 100% of the Scope 1 and 2 electricity use will be renewable.

-- 90% of GPU packaging will be recyclable materials in 2024

-- Has the goal to audit the activities of 100% of their strategic suppliers every two years

-- Reduced energy intensity in 2024 to 10.1 MWh/MM$ revenues

-- Has a landfill diversion rate of 71% in 2024

-- Had zero global fatalities in the 2022-2024 reporting years among the 29,600 employees.

ENERGY TRANSITION-DEMAND

The Role of Large Consumers

Apple:

-- Is committed to be carbon neutral by 2030.

-- Reduced in 2024 Scope 1, 2 and 3 emissions by 55% from 2015 levels

-- Has commitments from 320 suppliers representing 95% of the supplies to produce only with renewable energy

-- Uses 100% recycled cobalt in the batteries

-- 99% of the tungsten comes from recycled sources

-- Has a landfill diversion rate of 74% in 2024

ENERGY TRANSITION-GOVERNMENT

The Role of Government in Future Energy

The role of Government must change with the changes in the energy sector.

The past concept was that petroleum companies and power companies fulfilled rather separate and distinct roles. From a government point of view, they were managed separately.

In the future governments will need to manage the energy sector as a single sector with both petroleum and power companies producing ever increasing amounts of renewable energy. Economic growth will be determined by how successful governments are in supplying energy at the lowest possible costs. This means an optimal integration of all players in the sector.

ENERGY TRANSITION-GOVERNMENT

The Role of Government in Future Energy

This means the governmental structure must change in some countries. Rather than having petroleum and power in separate ministries, they should be managed in a single ministry, with directorates for petroleum, renewables and power, and where coal still plays a role, a directorate for coal.

Preferably there should be an energy planning department, although the market forces should be permitted to play the prime role in shaping the future. Implementation of climate change and energy efficiency policies belong also in this ministry.

In the following slides the current structures of some important petroleum producing countries will be reviewed. Many countries have already the recommended structure.

ENERGY TRANSITION-GOVERNMENT

The Role of Government in Future Energy

Following are examples of countries which do not have the recommended structure:

-- Saudi Arabia has a Ministry for Energy and for Water and Electricity. "Energy" primarily relates to petroleum,

-- Angola has a Ministry of Petroleum and for Water and Energy,

-- Qatar has a Ministry of Electricity and Water and one for Energy and Industry. "Energy" again means petroleum,

-- Nigeria has a Ministry of Petroleum and for Power, Works and Housing, and

-- the United States has a Department of Energy, but the management of the offshore petroleum and wind licenses is done in the Bureau of Ocean Energy Management ("BOEM"), a unit of the Department of the Interior.

ENERGY TRANSITION-GOVERNMENT

The Role of Government in Future Energy

Following are examples of countries which do have the recommended structure:

-- Mexico has a Secretary of Energy, with departments for Hydrocarbons and Power, as well as for R&D, energy policy and promotion of renewable energy,

-- Algeria has a Ministry of Mines and Energy, which includes, apart from mines, departments for hydrocarbons, electricity and gas distribution, renewable energy and environment,

-- Brazil has a Ministry of Mines and Energy, apart from mines, dealing with hydrocarbons as well as electricity,

-- Canada (Federal) has a Department of Natural Resources, that includes oil, gas, electricity and renewable resources, as well as departments for climate change, energy efficiency and R&D.

ENERGY TRANSITION-GOVERNMENT

The Role of Government in Future Energy

(continued):

-- Indonesia has a Ministry of Energy and Mineral Resources, which includes, apart from mines, departments for oil and gas, electricity, renewable resources and energy conservation, coal ad R&D.

-- the Netherlands has a Ministry of Economic Affairs and Climate Policy, which among many other functions includes electricity, gas and oil, sustainable heating and subsurface policies, climate and the Groningen surface structures project (do to the earthquake damage of gas production)

-- Norway has a Ministry of Petroleum and Energy, which includes directorates for Petroleum and for Water and Energy (in the case of Norway most electricity is from hydropower).

ENERGY TRANSITION-GOVERNMENT

The Role of Government in Future Energy

(continued):

-- Peru has a Ministry of Energy and Mines, with vice-minsters for petroleum and for electricity, as well as for mines,

--the UK has a department for Business, Energy and Industrial Strategy, which among many other functions includes oil, gas and electricity, energy efficiency and heat, low carbon generation, electricity and gas networks, energy and climate, climate change and smart meters and smart systems,

-- Russia has a Ministry of Energy, which deals with oil and gas, electricity, peat, shale resources, pipelines, renewable energy resources and petrochemical industries.

POLICIES

Energy Transition Policies

Assuming a country creates a Ministry for Energy, the next issue is than what the policies should be.

The following energy transition policies have as goal to manage an effective energy transition and achievement of climate goals resulting in fossil fuel production and consumption well below the levels forecasted in this presentation.

POLICIES

General Transition Policies

The general transition policies will consist of:

1. **Set a goal to achieve carbon neutrality by a certain date**
2. **Maintain an effective petroleum industry,**
3. **Promote midstream gas operations and feedstock production,**
4. **Carbon trading and carbon tax,**
5. **Eliminate subsidies and export duties,**
6. **Eliminate subsidies through corporate income tax,**
7. **Change petroleum land management,**
8. **Duration of petroleum arrangements.**
9. **Change qualification criteria for award and assignment**
10. **Promote gas over oil and coal,**
11. **Reduce energy emissions of the petroleum industry, and**
12. **Increase R&D.**

POLICIES

Set a goal for carbon neutrality by a certain date

A very important step for governments with respect to energy transition is to set a clear goal as to when carbon neutrality must be achieved. As discussed under "Climate Change", carbon neutrality is considered a condition of net zero emissions. The listing of countries, cities and companies adopting carbon neutrality was already discussed under "Climate Change".

It should be noted that setting such goals could have a major impact on producing oil and gas. In order to reach the climate goal Norway faces the choice of having to fuel offshore oil and gas fields with wind power or close the marginal fields down early in view of the fact that the industry is a major emitter of CO_2 during operations.

POLICIES

Maintain an effective petroleum industry

Even if we would manage to eliminate all fossil fuels by 2050, we still need a significant amount of oil and gas as feedstock for petrochemical industries, fertilizers and other purposes, unless green hydrogen costs drops very significantly.

However, it is likely that we will still need some jet fuel, marine bunker and natural gas for a variety of industries that are difficult to convert, such as the cement industry and iron and steel industry.

It is therefore likely that even with major achievements towards the 2 degrees scenario, fossil oil and gas production may still be half the VME estimates for 2050. This is still a large size petroleum industry.

POLICIES

Maintain an effective petroleum industry

At the same time is likely that by 2050 the petroleum industry will be a major contributor to the production of offshore wind, biofuels, hydrogen and possibly synthetic fuels.

In order to realize this production of renewable energy, investments of billions of US $ will be required. The petroleum industry would have to make maximum use of their skills of promoting large projects to realize these goals.

Therefore, the policy should be to maintain a healthy and efficient petroleum industry based on competitive practices and an effective regulatory system.

POLICIES

Midstream gas and feedstocks

As indicated in the presentation, natural gas and hydrogen can use the same gas pipeline and distribution infrastructure. Also, in the medium term a more widespread availability of gas will assist the development of wind and solar. Therefore, it is in the interest of the countries to establish this infrastructure, so over time hydrogen can replace natural gas.

This can be done in various ways. The ministry or regulator can establish a system of attractive pipeline tariffs and facilitate the acquisition of right of ways. Taxation should only be generally applicable taxes and some tax incentives could be applied.

POLICIES

Midstream gas and feedstocks

Countries with relatively significant rich gas resources could promote the production of petrochemical industries. Again, the costs of feedstocks are important. Therefore, relatively low cost NGL availability is an advantage.

Price controls cannot be recommended, since this is not a long-term sustainable solution.

Attractive fiscal systems for NGL's and possible fiscal incentives for establishing petrochemical industries are better policies.

POLICIES

Carbon Trading and Carbon Tax

Detailed information about carbon trading and taxation can be found in the annual World Bank Report, called "State and Trends of Carbon Pricing". The information in this presentation is based on the 2019 report.

In total there are 57 carbon pricing initiatives around the world, covering 46 national ad 28 subnational jurisdictions.

The carbon price varies between a low of about \$ 1/tCO2e (ton CO2 equivalent) in Mexico to \$ 127/tCO2e in Sweden, covering 11 GCO2e or about 20% of the world emissions (includes all GHG). About \$ 44 billion in carbon pricing revenues was received by Governments. The new government of Norway will establish a carbon tax of \$ 230/ton.

POLICIES

Carbon Trading and Carbon Tax

An economically attractive way to reduce CO2 emissions is to establish a CO2 trading system, whereby "permits to pollute" are traded among companies (an Emissions Trading System, "ETS"). Companies who are aggressively pursuing the reduction of carbon emissions will be rewarded by being able to sell their permits, while companies that are slow must purchase more permits.

Europe established an ETS, which crashed in 2016 as a result of having handed out too many permits. However, with the intervention of the European Parliament, the market has now recovered. The price in February 2022 the price was 100 Euro per ton. The scheme is highly successful. According to *the Economist* the industries covered by the ETS have reduced emissions by 47% since 2005.

POLICIES

Carbon Trading and Carbon Tax

An ETS is difficult to establish, since it requires a sophisticated approach to handing out permit to pollute and to establish the market. Carbon taxes are a simpler mechanism. Therefore, several countries have established carbon taxes.

In order to achieve the goals of the Paris Agreement the carbon price has to be between \$ 40 and \$ 80 per ton CO2 in 2020 and \$ 10 higher in 2030, as recommended in the Carbon Pricing Leadership Coalition ("CPLC") Report. The World Bank is concerned that most countries are well under the recommended level of carbon pricing.

The IMF recommends a carbon price of at least \$ 75/ton by 2030 in order to achieve the climate goals.

POLICIES

Carbon Trading and Carbon Tax

It can therefore be recommended that countries adopt the CPLC carbon tax ranges.

It is important to introduce these new taxes in a manner that is revenue neutral. In other words, the extra revenues to be received by government should be offset by reductions in other taxes and levies, to maintain the same tax level on the population; with special protection of low-income citizens.

The Canadian province of British Columbia has successfully followed this approach and started with a Can $ 30/ton tax in 2008 to be increased to Can $ 50/ton by 2021. Fuel consumption in the province has dropped by 16%, while the economy of the province has continued a strong growth.

POLICIES

Carbon Trading and Carbon Tax

It should be noted that the following section in this PowerPoint called "Country Energy Transition Status" provides an overview of the Carbon Taxes and Carbon Trading Policies of 50 different countries.

POLICIES

Carbon Taxes

Singapore has announced that it will implement the following carbon tax scheme:

Now - $ 5/ton

2025 - $ 25/ton

2027 - $ 45/ton

2030 - $ 50 - $ 80/ton

POLICIES

Carbon Pricing

The October 1 report of *the Economist,* reports that as of 2023 about 23% of the world emissions is now covered by some type of carbon pricing scheme.

Important initiatives have been taken in the European Union, Japan, China, South Korea, Indonesia and South Africa.

Vietnam may join in 2028.

Schemes are carbon markets and carbon taxes.

According to the World Bank countries raised a record $ 104 billion in carbon pricing in 2023.

POLICIES

Carbon Credits

A carbon credit is created through an offtake agreement with an entity that wishes to sell the CO_2 mitigation outcome of their activities.

There are two types of credits:

-- Removal credits – whereby the entity removes CO_2 from the atmosphere, in turn there are two subtypes:

**** the CO_2 is permanently stored, such as CCS, or**

**** the CO_2 is used to make a product, such as a salt**

-- Avoidance credits – where the entity prevents new CO_2 from entering the atmosphere, such as replacing a coal fired power plant with a solar energy plant.

POLICIES

Carbon Credits

For instance if an entity captures and stores 1000 tons of CO_2, it can enter into an offtake agreement and sell the positive effect that it has created. For instance, a purchasing company may wish to pay $ 25 per ton.

By paying $ 25,000 to the entity that captured and stored the CO_2, the company receives a certificate that it has paid for the removal of 1000 tons of CO_2. This is a “carbon credit”.

The company receiving the carbon credit can use this as an offset to possible other emissions it is creating, such as a power company burning natural gas. For instance, if the host government of the power company levies a carbon tax of $ 40 per ton. The power company can use the carbon credit to save $ 40,000 on 1000 tons it is emitting, and gains $ 15,000.

POLICIES

Carbon Credits

The Removal Credits consists of two separate activities:

--The capture of CO_2, which could be:

- ** biosphere assisted capture,
- ** capture of CO_2 from flue gases, or
- ** direct air capture

--The storage of CO_2, which could be:

- ** storage in underground reservoirs,
- ** storage as coal or dried plant material
- ** storage as salt in oceans
- ** storage in concrete

These matters were discussed in some detail under Carbon Capture and Storage

POLICIES

Voluntary Carbon Market

There is a Voluntary Carbon Market (”VCM”) managed by the World Bank in which carbon credits can be sold and purchased.

There is a wide variety of types of credits such as related to removal operations, forestry, agriculture, etc.

Early 2024 the costs of removal credits was in the range of US $ 40 - $ 1200 per ton and for avoidance credits US $ 9 - $ 25 per ton.

In 2023 in total about 250 million credits were issued.

It should be noted that in 2022 and 2023 the VCM suffered from a decline largely as a result of the fact that confidence in the market reduced due to a variety of poorly qualified projects, resulting in poor over-the-counter values for credits.

POLICIES

ITMOs

A major concern on the part of Removal Credit buying countries would be that the credits can be properly used for the purpose of the Nationally Determined Contributions ("NDCs") under the Paris Agreement.

For instance, it should be clear that the country in which the CO2 removals are created cannot count these against their NDC, only the purchasing country should be allowed to do so.

This can be dealt with through the creation of Internationally Transferred Mitigation Outcomes ("ITMOs") based Article 6.2 of the Paris Agreement. This involves bilateral agreements between the selling country and the purchasing country.

POLCIES

Standards

Another concern is to verify the true nature and the manner in which the project is carried for the carbon credit project and to make sure that the mitigation outcomes are properly assessed.

This can be achieved by ensuring that the project meets accepted standards.

An example is the Gold Standard of the Gold Standard Foundation in Geneva. This entity is specialized on community services and waste removal, renewable energy, land use and forests and blue carbon and wetlands, but does not seem to have standards for other carbon removal projects.

Another entity determining standards is VERRA.

POLCIES

Carbon Credit Trading

Once it is determined, by an independent validation and verification body the process, that indeed a valid project is proposed, the project can be certified by the Gold Standard Foundation or other similar agency.

All or some of the carbon credits of a certified project, or project that appears otherwise acceptable to a buyer, can be sold through a “Emissions Reduction or Removal Purchase Agreement”. Once the buyer owns the carbon credits, these can be sold onwards through a trading agreement based on a “Standard Master Trading Agreement”.

POLICIES

Carbon Offsets

A Thai electric bus operator has sold carbon offsets to a Swiss fossil fuel group.

The Swiss Klik Foundation is had purchased in December 2023 a total of 1916 carbon credits from the Thai Energy Absolute.

Energy Absolute is generating the credits by creating a fleet of 4000 electric buses in Bangkok.

POLICIES

Fiscal Stability

It should be noted that in some countries with production sharing contracts or other petroleum agreements, the introduction of carbon taxes would be prohibited because of fiscal stability provisions. It is therefore essential that modern petroleum agreements exclude the following taxes from fiscal stability (unless discriminatory against the contractor):

(a) generally applicable taxes, such as corporate income tax,

(b) levies, taxes or payments to comply with modern principles in respect of environment, labor laws, health and safety, and

(c) new taxes, levies or duties to implement commitments with respect to climate change under the Paris Agreement and other international agreements.

The Nigeria Petroleum Industry Act has established this principle.

POLICIES

CBAM

Countries at different stages of implementation of climate policies create an import/export problem. Countries that are weak at implementing climate policies would export products that are relatively carbon intensive to countries that have more stringent policies.

As a result, the European Union is working on a carbon border adjustment mechanism ("CBAM") in order to prevent such "carbon leakage".

POLICIES

Eliminate subsidies and export duties

It is obvious that under a rational climate policy the first objective should be to eliminate actual and implied subsidies of fossil fuels. This means the elimination of:

1. **actual subsidies to consumers,**
2. **domestic market or domestic supply obligations,**
3. **price controls resulting in artificially low prices, and**
4. **Export duties.**

POLICIES

Eliminate subsidies and export duties

Actual subsidies for oil, gas and fossil fuel-based electricity to consumers is still a massive issue around the world. The IEA estimates that in 2018 the total amount of subsidies was about $ 400 billion in 25 countries, in some cases representing a large share of the GDP. Following are examples:

-- Iran - $ 69.2 billion

-- Saudi Arabia - $ 47.7 billion

-- China - $ 43.3 billion

-- Russia - $ 36.2 billion

-- Indonesia - $ 31.3 billion

-- Egypt - $ 26.5 billion

POLICIES

Eliminate subsidies and export duties

It should be noted that such subsidies create often a substantial burden on the government budget with the result of not being able to fully commit to other matters such as education and infrastructure development.

POLICIES

Eliminate subsidies and export duties

Some countries, such as Nigeria, Malaysia, Indonesia and Egypt, have domestic market or domestic supply obligations, requiring petroleum companies to supply the domestic market on the basis of low prices.

It is a logical obligation for petroleum companies which operate in any country to supply the domestic market. Domestic markets are sometimes more complex to enter than simply exporting oil or gas.

However, companies should not be required to supply these markets for artificially low prices or for pricing regimes that would not reasonably bring forward an adequate supply on an economic basis.

POLICIES

Eliminate subsidies and export duties

Some countries, such as Saudi Arabia, Angola, Venezuela and Algeria have very low regulated prices for associated natural gas or even non-associated natural gas.

Such policies are not consistent with an effective energy transition policy.

Prices should be at a level that brings adequate supplies forward to the domestic market on a fully economic basis. In this respect it should be noted that even the collection, transport and processing of associated natural gas requires considerable investment and associated gas therefore cannot be "free".

POLICIES

Eliminate subsidies and export duties

A number of countries have significant export duties, such as Russia, China, Malaysia, Vietnam and Argentina.

Export duties mean by definition lower domestic prices than international prices. This is therefore a mechanism of indirectly subsidizing domestic markets.

It can be recommended to eliminate such export duties. Argentina and Russia have both made significant progress in this area.

Eventual elimination and replacement of export duties by an adequate fiscal structure, to maintain government revenues, can be recommended.

POLICIES

Eliminate subsidies through corporate income tax

Nations can elect to have a high or low corporate income tax rate. The level does not imply a subsidy. However, in a number of cases subsidies are implied through favorable corporate income tax treatment for the petroleum industries compared to other taxpayers in the country. It can be recommended to eliminate such subsidies.

An example of this is the percentage depletion allowance that still exist in the United States for small companies. Also, Spain, Pakistan and Paraguay apply depletion allowances for the general petroleum industry. However, in the case of Pakistan the tax rate to the petroleum industry is higher than the general rate.

POLICIES

Eliminate subsidies through corporate income tax

(continued:)

The Central African Republic also has an investment credit and depletion allowance.

Jamaica and Morocco apply 10-year tax holidays for the petroleum industry.

Saudi Arabia (on the gas agreements), South Africa and Trinidad and Tobago feature uplifts for tax purposes, although T&T has a higher tax rate for the petroleum industry.

The UK features a ringfence expenditure supplement.

POLICIES

Petroleum land management

Under the VME estimate, by 2050 the world will still have a petroleum industry producing significant volumes of crude oil and natural gas. Therefore, countries can still benefit from the economic rent and economic activity of the petroleum industry by making acreage available in licensing rounds or based on application systems.

It is a good policy, however, to avoid offering areas with a high social or environmental costs, such as rain forest areas.

Also, in anticipation of ever lower oil and gas prices, promotion of expensive areas such as Arctic areas, ultra-deep water, extra-heavy oils, etc. should be avoided.

POLICIES

Petroleum land management

Certain nations have elected to terminate further acreage licensing, as a logical consequence to achieve a carbon neutral economy by 2050, as also recommended by in the IEA Roadmap for 2050. Thirteen nations and five jurisdictions have established this policy:

-- New Zealand, Denmark, Ireland, Sweden, Iceland

-- Portugal, Spain, France (incl. French Guiana, other territories)

-- Colombia (as of 2023),Belize, Costa Rica, Tuvalu, Vanuatu

-- Greenland, California, Quebec, Wales, Washington State

Costa Rica and Denmark launched the Beyond Oil and Gas Alliance ("BOGA") of nations at the COP26.

However, New Zealand is planning in 2024 to reverse the policy.

POLICIES

Petroleum land management - UK

The UK Labor Party also plans a blanket ban on new oil and gas developments in the North Sea if they achieve power.

If so, the 300 million barrels Rosebank field, west of Shetland, may be the last field to be developed in the North Sea. The field is scheduled to start producing in 2026 and production will last until 2050, with a peak production of 700,000 bopd.

POLICIES

Petroleum land management

As was discussed above under "Climate Change" many oil and gas producing countries are likely to continue to offer new acreage, in some cases despite well defined climate policies. An interesting example is Norway. Norway passed the Climate Change Act which mandates a reduction of emissions by 2050 of 90 – 95%.

Yet at the same time Norway published in June 2021 an Energy White Paper, which calls for continued offering of exploration acreage. Assuming this takes place over the next 5 years, with an exploration phase of 10 years and production phase of 30 years, Norway will still be producing petroleum by 2065.

Likewise Saudi Arabia intends to remain the largest exporter despite claiming carbon neutrality by 2060.

POLICIES

Duration of Petroleum arrangements

An important issue is the duration of leases, licenses and contracts.

In North America and Europe, it is typically the practice that licenses and leases can be continued until the exhaustion of the resource with renewals being granted under prevailing conditions.

In countries with production sharing contracts and other contractual arrangements, contracts often have a finite duration, including one or two possible renewals. The worldwide average, total duration is about 32 years.

POLICIES

Duration of petroleum arrangements

The idea of finite contracts is that it encourages a company to produce the petroleum rapidly. It is sometimes contemplated that at the end of the contract the national petroleum company takes over and becomes 100% owner or that a bid round be held to get improved terms for the remainder of the contract.

None of these concepts makes sense under petroleum transition policies. Petroleum should be produced at the most economic rate, resulting in the highest recovery factor. By 2050 national petroleum companies are unlikely to find an attractive environment to continue petroleum operations, while it cannot be expected that high bids will be received at that time for producing fields.

POLICIES

Duration of petroleum arrangements

It can therefore be recommended that also in countries with contractual arrangements, contracts will continue to be renewed until the exhaustion of the resource.

In particular in countries where production is linked to increased fertilizer and petrochemical production it is of importance that oil and gas production continuous normally in order to provide incentives to petroleum companies to invest in the related midstream facilities.

It is also of great importance that petroleum companies take full responsibility for proper decommissioning and abandonment upon the exhaustion of the resource.

POLICIES

Qualification Criteria

So far it has been a regular policy of governments that acreage can only be awarded and interests can only be assigned to companies that are technically and financially qualified.

From now on an important additional qualification criterion will be whether companies are qualified in terms of energy transition. Companies should have credible energy transition plans and capabilities in order to operate in a country.

This can be best measured with the energy intensity discussed earlier. For instance, a company energy transition plan should contemplate gradual reductions of energy intensity from the current level (say 80 tons per TJ) to as a maximum 40 tons per TJ by 2050 (or less), based on a Scope 1, 2 and 3 approach.

POLICIES

Promotion of gas over oil and coal

CO_2 emissions associated with the burning of one million Btu are as follows:

-- 98 kg for coal,

-- 77 kg for oil, and

-- 58 kg for natural gas.

This means that emphasizing the production of natural gas over oil and coal is generally beneficial.

Also, natural gas will over the next decade(s) integrate well with increased solar and wind production in order to provide electric grid stability during periods of no sun and no wind (until utility scale battery storage becomes cheaper).

POLICIES

Promotion of gas over oil and coal

It should be emphasized that during the production of associated gas with oil and non-associated gas, it is a great importance to have very strict provisions to avoid the escape of methane in the atmosphere.

This is an area where countries must significantly improve performance.

Based on the 100-year Global Warming Potential (“GWP”) one kg of methane has the same global warming effect as 25 kg of CO_2.

The production of natural gas over oil can be emphasized through the fiscal terms or through the licensing process.

POLICIES

Promotion of Gas over Oil and Coal

Table 6.10.1. Jurisdictions with Gas-Favourable Fiscal Terms			
Argentina	Egypt	Malaysia	Senegal
Australia	Ethiopia	Mali	Sierra Leone
Belize	France	Morocco	South Sudan
Benin	Ghana	Nicaragua	Sudan
Brunei	Guatemala	Niger	Tanzania
Cambodia	India	Nigeria	Thailand
Cameroon	Indonesia	Oman	Trinidad & Tobago
Canada - Alberta	Iraq - Kurdistan	Pakistan	Tunisia
Canada - British Columbia	Kazakhstan	Papua New Guinea	USA-Arkansas
Canada - Nfld. & Lab. (Proposed)	Kyrgyzstan	Paraguay	USA-Louisiana
Canada - Nova Scotia	Laos	Poland	USA-Michigan
Central African Republic	Latvia	Portugal	USA-North Dakota
Chad	Lebanon	Qatar	Venezuela
China	Liberia	Russia	Vietnam
Colombia	Libya	Sao Tome & Principe	Zambia
Cote de I'voire	Madagascar	Saudi Arabia	

Explanation:
Gas-Favourable means that the fiscal systems include fiscal features which are lower for gas than for oil, such as lower royalties for gas than for oil. In case of sliding scales sometimes the system includes an attractive energy conversion factor for gas. Production sharing contracts could have lower profit gas and higher cost gas. Windfall profit features, excise taxes or other taxes may apply to oil but not to gas. Some favorable features apply to shale gas or CBM.

The above table shows a table from a Van Meurs report illustrating the jurisdictions that have already gas-favorable fiscal terms.

POLICIES

Reduce petroleum industry emissions

Currently the petroleum industry contributes to 15% of the total energy related emissions for an equivalent of 5.1 billion tons of CO_2. it is therefore imperative to reduce these emissions. This can be done through:

-- tackling methane emissions,

-- eliminate routine flaring,

-- electrify upstream and midstream facilities,

-- promote carbon capture and storage, and

-- use green hydrogen in refining.

***The Economist* estimates that for US $ 600 billion the emissions can be reduced by 50% by 2030.**

POLICIES

50 companies sign pledge

An important result of COP28 is that 50 petroleum companies signed a pledge, by 2050 involving Net Zero based on Scope 1 and 2 emissions, and by 2030 reducing methane emissions to less than 0.2% of oil and gas production and eliminate routine flaring.

Companies include National Oil Companies, such as ADNOC, Equinor, KazMunaiGaz, OMV, Pertamina, Petoro, Petrobras, PTTEP, Saudi Aramco and SNOC.

International Oil Companies include BP, Crescent, ENI, ExxonMobil, Lukoil, Occidental, Repsol, Shell and TotalEnergies.

Not signed include KOC, QatarEnergy, CNOOC, Petrochina, NIOC, and Chevron.

POLICIES

Reduce petroleum industry emissions - Reduce flaring

Non-routine flaring is integral to petroleum operations for well testing, facilities overhaul, safety and other reasons. Nevertheless, such non-routine flaring should result in carbon taxes and possible other payments in order to encourage the minimum amount of flaring.

Routine flaring should be prohibited and subject to penalties. Sometimes, gas contains significant quantities of CO_2. Such CO_2 is being removed. Venting of such CO_2 should also be prohibited.

Unfortunately, routine flaring is still occurring in considerable amounts. For instance, Nigeria still flares almost a billion cubic feet per day.

POLICIES

Reduce petroleum industry emissions- carbon capture and storage

Considerable efforts are being undertaken by a wide variety of petroleum companies and power companies to promote carbon capture and storage ("CCS").

Such efforts should be promoted by governments.

Carbon taxes are an inducement, but at this moment CCS is rather expensive and therefore other more stringent measures are required, such as simply prohibiting CO2 emissions as part of the approval of a project.

CCS does not have to be associated with fossil fuels. It can be done directly based on a variety of methods.

POLICIES

Reduce petroleum industry emissions - carbon capture and storage

The promotion of CCS is in particular important where certain industries, such as the cement industry, will be unable to avoid releasing large volumes of CO_2.

In this respect Equinor, Shell and Total are constructing the "Northern Lights" project that will take the CO_2 from a cement factory and other Norwegian industries to a terminal on the West coast of Norway and ship it in liquid form by pipeline to inject this in a special well drilled for this purpose to a specific reservoir for permanent storage. The reservoir is 2500 meter deep and located South of the Troll field.

POLICIES

Reduce petroleum industry emissions - carbon capture and storage

Of particular importance for climate policies of governments is to encourage BECCS and DAC as complementary operations to petroleum activities.

Petroleum legislation should link to or include the matters related to carbon capture and storage, so petroleum companies operating certain fields or reservoirs can carry out these activities either as operations in conjunction with petroleum operations or as stand-alone operations.

POLICIES

Reduce petroleum industry emissions – upstream renewables

The upstream petroleum industry uses considerable energy to produce oil and gas fields, as much as 3 – 7% of the production. Therefore, providing renewable energy for production is very important.

Norway is already providing offshore installation with onshore hydropower.

In the UK, Cerulean Winds in planning an integrated supply system based on wind generation in three sites and providing the oil producers access to the renewable energy through High Voltage Alternating Current (HVAC) transmission. High Voltage Direct Current (HVDC) transmission will be used to export any excess.

POLICIES

Reduce petroleum industry emissions – LNG renewables

The liquefaction of natural gas requires significant volumes of electricity.

This can be generated from renewable sources.

An interesting example is the Pacific Energy Woodfibre LNG project to be producing 2.1 million tons of LNG by 2027.

This project will be fueled with hydropower from British Columbia.

POLICIES

Promote R&D

As will be obvious from this entire presentation further R&D will dramatically impact on the energy transition framework. R&D efforts are very important in:

-- increasing solar panel efficiency,

-- wind power efficiency,

-- creating improved cheap batteries,

-- producing cheap hydrogen,

-- finding ways for cheap CCS, and

-- development of entirely new concepts.

Therefore, promotion of R&D as is currently done by a wide range of governments and companies is the key to a successful future.

POLICIES

Promote R&D

The recent IEA Report "Energy Technology Perspectives, 2020" lists four specific examples where R&D could accelerate the energy transition, as follows:

-- advanced battery chemistries and recycling techniques: battery cells with an energy density of 800 Wh per KG, three times the current lithium-ion batteries, for instance based on lithium-sulfur or lithium-air, could significantly expand the role of batteries in the air transport and heavy transport sector and other applications. Better recycling techniques could conserve lithium.

-- direct electrification of primary steel production: based on technically feasible processes, but not yet applied on a large scale.

POLICIES

Promote R&D

-- techniques to expand the sustainable biomass supply for the purposes of making biofuels and biochemicals: such as through crops with higher yields and the use of new biomass resources, such as algae and aquatic biomass. Applications would be for aviation, shipping and cement production.

-- advanced refrigerant free cooling: energy efficiency improvements in advanced evaporative cooling and solid-state cooling (and heating) could improve energy use in the residential and commercial sectors.

COUNTRY ENERGY TRANSITION STATUS

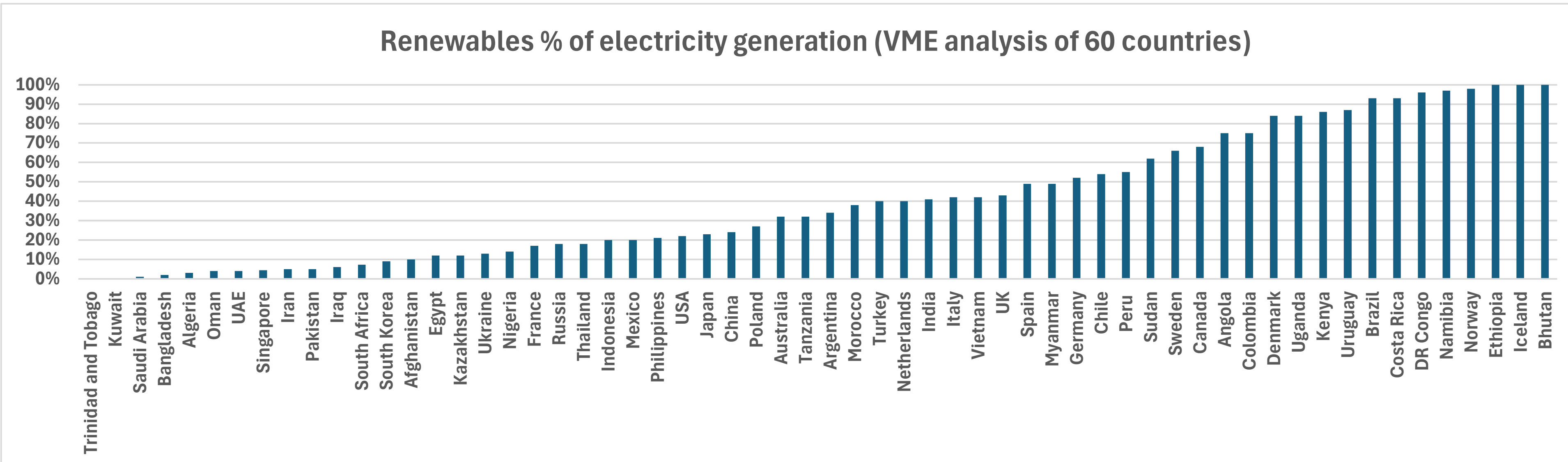
Country Selection

The country energy transition status review consist of a selection of 600 countries selected from all continents based on a varying transition. It includes all countries with more than 40 million people.

For each of the countries four items were studied: (1) the percent renewables in the total power generation, (2) the percentage EV's in new car sales, (3) the current operating production of green hydrogen, and (4) carbon taxes and carbon trading

COUNTRY ENERGY TRANSITION STATUS

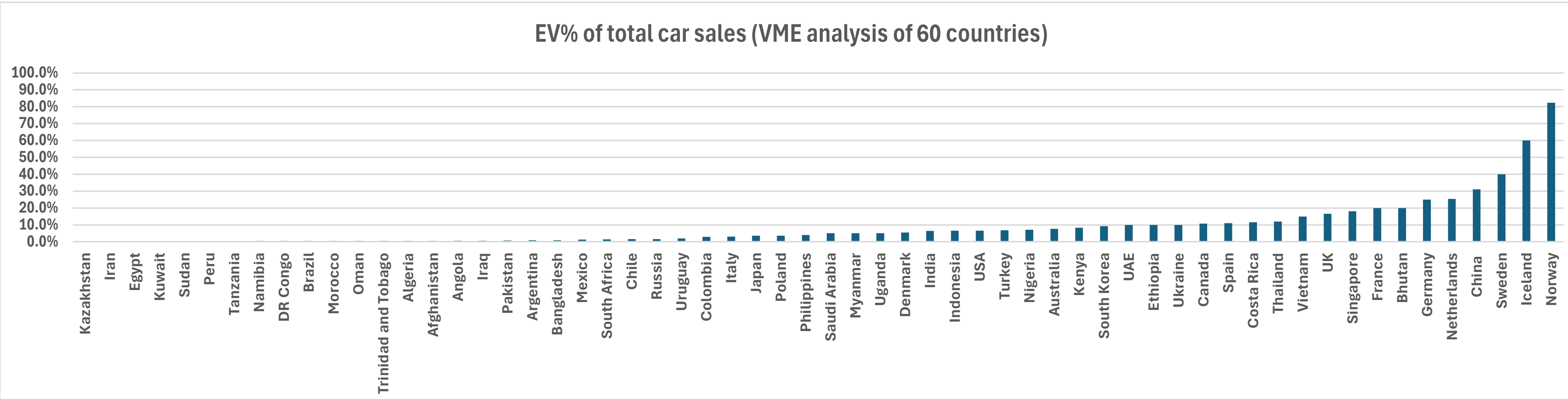
Percent Renewables in Power Generation



Only 20 countries feature a percent renewables of more than 50%. This is in most cases due to the importance of extensive hydropower generation.

COUNTRY ENERGY TRANSITION STATUS

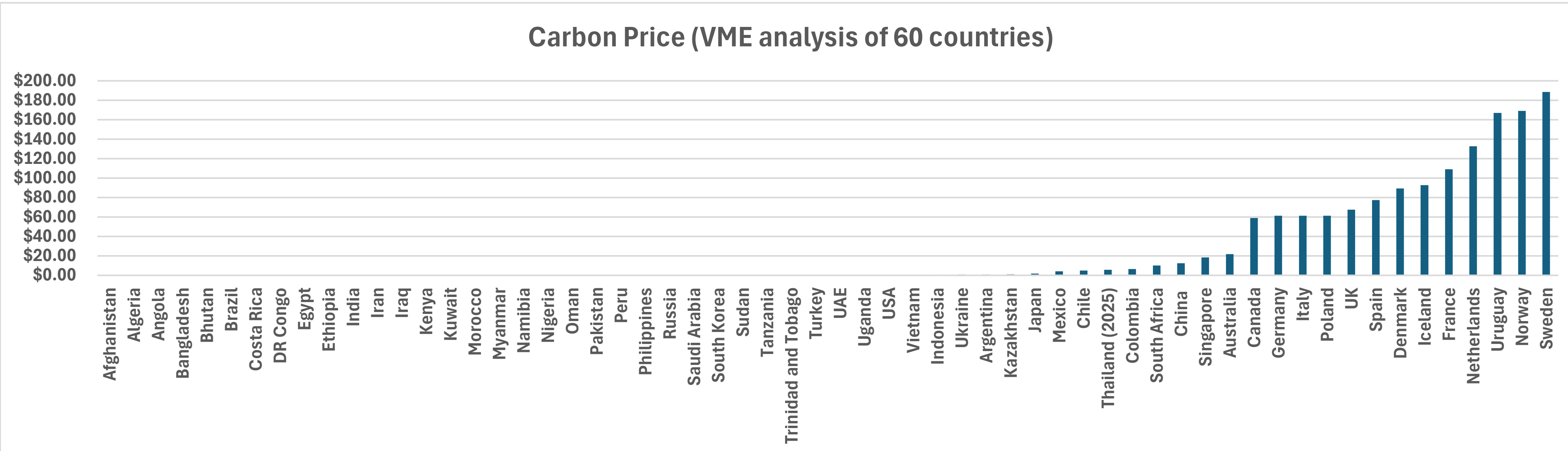
Percent EV's in new car sales



Only 18 countries feature a percent EV's of more than 10%. The high penetration in Norway is caused by the fact that electric vehicles up to a value of $ 47,500 are free of the 25% VAT.

COUNTRY ENERGY TRANSITION STATUS

Carbon Price



Only 17 countries feature a carbon price of more than US$ 10 per ton CO2. The carbon price is either a carbon tax or the market value of carbon trading or both.

COUNTRY ENERGY TRANSITION STATUS

Current Green Hydrogen Production

The current level of operating green hydrogen production is extremely low. Only 4 countries produce 4000 tons per year or more: Spain, Italy, the United States and China.

This is despite a large worldwide pipeline of projects of millions of tons per year in total. As many as 12 countries have plans for more than 1Mt/y of green hydrogen or green ammonia: Saudi Arabia, Oman, UAE, Egypt, Kazakhstan, USA, China, Australia, India, Canada, Namibia and Brazil.

According to Adithya Bhashyam of BloombergNEF this is because 60% of the project are in the early stages of planning without detailed engineering. Also lack of government policies is holding things up.

COUNTRY ENERGY TRANSITION STATUS

Record achievements or projects in some countries

Algeria: hydrogen pipeline for Algerian gas to Germany

Australia: Western Green Energy Hub: 50 GW wind/solar, 3.5 MMtons green hydrogen

Bhutan: statistically carbon neutral

Bolivia: Exomad Green Biochar removing 200,000 tons CO2/y

Brazil: 6507 MW Ventas do Sul- offshore wind

China: Shanxi solar and wind – 6 GW with 3.4 GWh or storage

Egypt: Masdar 10 GW of onshore wind in West Suhag

Ethiopia: 100% renewable power

COUNTRY ENERGY TRANSITION STATUS

Record achievements or projects in some countries

France: Discovery of 46 million tons of white hydrogen in Lorraine

Germany: Boxberg by LEAG – largest Europa renewable energy hub 7GW

Iceland: ORCA 4000 ton/y CO2 DAC plant

India: Adani Green Renewable Park Khavda, Gujarat – 30 GW

Indonesia: 145 MW Floating Solar in Cirata reservoir West Java by Masdar

Italy: Energy Dome 20 MW/200MWh CO2 battery in Sardinia

Laos: 5000 MW Geothermal project for export to Vietnam

Morocco: Noor Ouarzazate CSP at 580 MW

Myanmar: 6000 MW Myitsone Dam hydro operating on Irawaddy River

COUNTRY ENERGY TRANSITION STATUS

Record achievements or projects in some countries

Netherlands: 4 GW award of offshore wind in two projects

Norway: EV sales percent: 82.4% (2023) of total car sales

Norway: Northern Lights CCS project

Oman: Hydrom 1 Mt/y green hydrogen near Duqm on 1500 sq km

Poland: 7 km deep geothermal well in Szaflary

Pakistan: 4320 MW Dasu Dam hydro project under construction

Saudi Arabia: ACWA NEOM project 1.2 Mt/y green ammonia by 2026

Sweden: Highest carbon price at US $ 188.56/ton CO2

Singapore: Tuas CCS using the Equatic process 110,000 tons CO2 per year

COUNTRY ENERGY TRANSITION STATUS

Record achievements or projects in some countries

South Korea: 1200 MW Seamangeum offshore floating solar project

South Korea: 3200 MW Jindo offshore wind farm cluster by Pacifico Energy Korea

Turkey: 3000 MW Kalyon Karapinar Solar Project by Kalyon

UAE: Al Maktoum – CSP based solar park – 4600 MW in Dubai

UK: Dogger Bank offshore wind – 3600 MW by SSE Renewables

USA: The Geysers – geothermal complex, 1510 MW, by Capine

Uruguay: Carbon Tax: US $ 167.17, Coverage: 4%

Vietnam: 3500 MW La Gan offshore wind project for 2026

COUNTRY ENERGY TRANSITION STATUS

Afghanistan – Carbon Neutral: 2050

Electricity: renewables: 10% (mainly hydro), imports 88%

EV sales percent: < 1%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0,

Carbon Trading: No

Renewable projects:

-- 100 MW Naghlu hydro plant in Kabul province operating

-- 200 MW Dur Baba solar plant project in Nangarhar province

-- 300 kW West Herat wind project in Herat province

COUNTRY ENERGY TRANSITION STATUS

Algeria – Carbon Neutral: No target

Electricity: renewables: 3%, natural gas: 96%

EV sales percent: < 1%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0, OPEC opposes carbon tax

Carbon Trading: No

Renewable projects:

-- 10 MW solar by Sonatrach to support oil fields in the Hassi Berkine basin

-- SoutH2 Corridor project of hydrogen pipeline through Italy to Germany

-- 220 MW solar by PowerChina in Bir Naam

-- Sonelgaz tender for 15 PV plants with total capacity of 2000 MW

COUNTRY ENERGY TRANSITION STATUS

Angola – Carbon Neutral: No target

Electricity: renewables: 75% (mainly hydro), remainder fossil fuels

EV sales percent: < 1%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- Barro do Dande green hydrogen export project of 280,000 tons/y by Gauff and Conjuncta with Sonangol, electricity from the 2GW Lauca hydro project

-- 2172 MW Cacula Cabaca hydro project in Lunda Norte by China Gezhouba.

-- 50 MW Caraculo solar park in Namibe Province by ENI

-- 30 MW Gastao wind farm in Cuanza Norte

-- 188 MW BioPio solar park in Benguela by M Couto Alves Vias

COUNTRY ENERGY TRANSITION STATUS

Argentina – Carbon Neutral: 2050

Electricity: renewables: 34% (22% is hydro, 12% renewables), natural gas: 59%

EV sales percent: 0.8%

Green hydrogen production per year (2023): 96 tons/y

Carbon Tax: US $ 0.81, Coverage: 38%

Carbon Trading: Under consideration

Renewable projects:

- **223 MW Puerto Madryn onshore windfarm by Patagonia Wind Energy**
- **300 MW Hive San Luis Solar Park for 2026 by Hive Energy**
- **Hychico small green hydrogen generator in Patagonia**
- **Fortescue Metals green hydrogen plant for 35,000 ton/y in Rio Negro**
- **Hombre Muerto West lithium project by Galan Lithium**

COUNTRY ENERGY TRANSITION STATUS

Australia – Carbon Neutral: 2050

Electricity: 272 TWh (2022) – 32% renewable, 47% coal

EV sales percent: 7.6% (2023)

Green hydrogen production per year (2023): 5 tons/day

Carbon Tax: US $ 0,

Carbon Trading: US $ 21.90, Coverage: 26%

Renewable projects:

-- Western Green Energy Hub: 50 GW wind/solar, 3.5 million tons/year green hydrogen in the 2030's

-- Queensland Hysata project hydrogen technology (> $ 1.50/kg)

-- Queensland 250MW/500MWh Swanbank Battery

-- Pilbara Hydrogen Hub – 492000 tons/year hydrogen by 2029

-- Victoria 5 GW offshore wind by EnergyAustralia

-- Pilbara Rio Tinto Aluminum 1 GW wind

-- Has approved an export project of solar electricity to Singapore through a 4300 km undersea cable

COUNTRY ENERGY TRANSITION STATUS

Bangladesh – Carbon Neutral: 2050

Electricity: renewables – 2%, Gas- 60%, coal – 13%

EV sales percent: < 1%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- 500 MW wind project in Cox Bazar by CIP

-- 275 MW Beximco Gaibandha solar by TBEA Xinjiang Sunoasis and Beximco

-- 500 MW offshore wind by CIP

COUNTRY ENERGY TRANSITION STATUS

Bhutan – Carbon Neutral: already statistically carbon neutral

Electricity: renewables - 100% hydro

EV sales percent: 20%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- Huge hydro potential of 33GW

-- 7240 GWh hydro exports to India in 2022 with 204 GWh imports

-- 1020 MW Tala hydropower plant is currently largest plant

-- Punatchangchhu-I and II will add 2338 MW

-- 500 kW ground mounted solar installed in Timphu by BSIP.

-- 310 MW new hydro and solar to be installed to provide grid security during dry times.

COUNTRY ENERGY TRANSITION STATUS

Brazil – Carbon Neutral: 2060

Electricity: 583 TWh (2020) – 93% renewable (mainly hydro)

EV sales percent: 0.5% (2023)

Green hydrogen production per year (2023): 156 tons

Carbon Tax: US $ 0

Carbon Trading: under consideration

Renewable projects:

-- Energix Energy will construct a hydrogen plant in Ceará to produce 600,000 tons of green hydrogen targeted for 2025

-- Brazilian State of Ceará and Grupe Jepri plan a 1.2 million ton/year green hydrogen plant starting production 2027

-- Ventos do Sul offshore wind farm 6507 MW planned for 2027 production, 482 turbines, 13.5 MW each

-- Ventos do Atlantico – 5009 MW wind planed for 2029 production

COUNTRY ENERGY TRANSITION STATUS

Canada – Carbon Neutral: 2050

Electricity: 636 TWh (2020) – 68% renewable (mainly hydro)

EV sales percent: 10.8% (2023)

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 58.95, Coverage: 31%

Carbon Trading: US $ 58.95, Coverage: 1%

Renewable projects:

-- World Energy GH2 Newfoundland 0.25 Mt/y H2, 1.2 Mt/y ammonia probably by 2026

-- Quebec TES Energy 70,000 tons green hydrogen/year by 2028

-- Ontario Ameresco and Atura Power 250 MW/1000 MWh BESS

-- Floating wind Nova Scotia – 300 to 400 MW by 2030

-- 4.2 GWh solar for the Rio Tinto Diavik Diamond mine NWT

-- ACTL 14.6 Mt/y CCS operating project

COUNTRY ENERGY TRANSITION STATUS

Chile – Carbon Neutral: 2050

Electricity: 88 TWh (2020) – 54% renewable, 22% coal

EV sales percent: 1.5% (2023)

Green hydrogen production/y (2023): 175,000 e-Methanol

Carbon Tax: $ 5.00, coverage: 55%

Carbon Trading: No

Renewable projects:

-- Atacama desert 180 MW solar and 112 MW storage by AEC corporation,

-- HIF Cabo Negro: 175,000 e-Methanol per year

-- Cerro Dominador 110 MW of CSP in Atacama

-- Horizonte onshore wind project 778 MW in Antofagasta producing in 2024

-- Longest powerline 1342 km Antofagasta –Santiago by CSG

COUNTRY ENERGY TRANSITION STATUS

China – Carbon Neutral: 2060

Electricity: 8500 TWh (2021) – 24% renewable, 62% coal

EV sales percent: 31% (2023)

Green hydrogen production per year (2023): 20,000 tons (Kuqa City at $ 2.50 per kg)

Carbon Tax: US $0

Carbon Trading: $12.57, Coverage: 32%

Renewable projects:

-- Huanghe Hydropower Hainan Solar Park – 2200 MW – 202.8 MW/MWh storage(2020)

-- Hinggan League onshore wind – 3000 MW (2023)

-- Shanwei Jiazi I+II (2022) – 900 MW

-- Huainan Floating Solar PV, Anhui – 40 MW (2017)

-- Shanxi solar and wind – 6 GW with 3.4 GWh of storage - $ 7.7 billion, planned on old coal mine to supply Beijing

COUNTRY ENERGY TRANSITION STATUS

Colombia – Carbon Neutral: 2050

Electricity: renewables – 75% (73% hydro, 2% wind and solar), 14% gas

EV sales percent: 2.9%

Green hydrogen production per year (2023): < 1 ton/y

Carbon Tax: US $ 6.68, Coverage: 20%

Carbon Trading: under development

Renewable projects:

-- 1.5 MW floating solar in Urrá reservoir by Noria Energy

-- 102 MW Portón del Sol solar project in La Dorada by Enerfin

-- 20 MW Guajira wind farm in Uribia

-- 50 MW Nereidas Valley geothermal project by Ecopetrol and others

-- 238 MW of solar by Efigen under contract with PowerChina

-- Promigas 20 kW PEM electrolyser injecting hydrogen in Cartagena

-- Ecopetrol exploration confirmed seepage of white hydrogen

COUNTRY ENERGY TRANSITION STATUS

Costa Rica – Carbon Neutral: 2050

Electricity: renewables – 93% (69% hydro, 12% wind, 11% geothermal,1%other)

EV sales percent: 11.6%

Green hydrogen production per year (2023): 0

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- 163 MW Miravalles geothermal operating owned by ICE

-- 55 MW Borinquen I geothermal project being developed by ICE

-- 5 MW Solar by BMR Energy

-- DLZ Hydrogen LATAM with a 600 ton/day green ammonia project for 2027

-- 50 MW wind operating in Orosi.

COUNTRY ENERGY TRANSITION STATUS

Democratic Republic of Congo – Carbon Neutral: 2050

Electricity: renewables – 96% (all hydro)

EV sales percent: < 1%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- The country has a huge cheap hydropower potential and therefore potential for green hydrogen.

-- 1424 MW Inga II largest hydropower plant in Congo River

-- 14 MW Essor Solar project in Gemena by AEE Power and others

-- 8 MW minigrid in Bunia

COUNTRY ENERGY TRANSITION STATUS

Denmark – Carbon Neutral: 2045

Electricity: 35 TWh (2023) – 84% renewable

EV sales percent: 5.5% (2023)

Green hydrogen production per year (2023): 70 tons

Carbon Tax: US $ 28.21, Coverage: 48%; to be increased by 2030 to US $ 108 for items not covered by ETS and to US $ 54 for items covered by ETS

Carbon Trading: US $ 61.30, EU Coverage: 38%

Renewable projects:

-- Plug Power Holstebro Green Hydrogen 15,700 tons/y in 2027.

-- Esbjerg Green Energy project – 1 GW green hydrogen by 2028

-- 12 Ha Energy Hub Island – 3 GW first phase wind, 10 GW final

-- Ørsted will start 530,000 ton BECCS project from its biomass plants

-- Ørsted has 7 large biomass plants for electricity and heat

-- Government has approved procurement for wind power expansion to 6 GW by 2030

COUNTRY ENERGY TRANSITION STATUS

Egypt – Carbon Neutral: No target

Electricity: 179 TWh (2023) – 12% renewable, 55% natural gas

EV sales percent: 0.1% (2023)

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- Indian ACME plans $ 12 billion 2.2 Mt/y green hydrogen.

-- Masdar 10 GW of onshore wind in West Suhag

-- Scatec plans 100,000 of green methanol by 2027 for Suez canal

-- Benban solar park 1650 MW between Aswan and Cairo on 27.2 sq km.

-- Ocior $ 4 billion green hydrogen project at Suez canal

COUNTRY ENERGY TRANSITION STATUS

Ethiopia – Carbon Neutral: 2050

Electricity: 100% renewables (96% hydro, 4% wind)

EV sales percent: 10%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- Grand Ethiopian Renaissance Dam in the Nile – 6000 MW

-- 300 MW Aysha windfarm of UAE AMEA Power

-- 25 MW Aluto Langano geothermal project

-- 150 MW Oromia geothermal project by Corbetti Geothermal PLS

-- 125 MW EEP Solar PV Park in Somali by ACWA

COUNTRY ENERGY TRANSITION STATUS

France – Carbon Neutral: 2050

Electricity: renewables – 17%, nuclear – 75%

EV sales percent: 20%

Green hydrogen production per year (2023): 575 tons/y

Carbon Tax: $ 47.94, Coverage: 40%

Carbon Trading: $ 61.30, EU Coverage 38%

Renewable projects:

-- Discovery of 46 million tons of white hydrogen in Lorraine

-- 34 tons/day green hydrogen project in La Havre by Lhyfe

-- 496 MW offshore wind operating in Saint-Brieuc bay by Iberdrola

-- 96 MW Ensemble Catalan onshore wind by EDF Renewables

-- 300 MW Cestas Solar Park by Neoen

-- Lithium license in Bas-Rhin for Lithium de France

COUNTRY ENERGY TRANSITION STATUS

Germany – Carbon Neutral: 2045

Electricity: 51.8% renewables in 2023

EV sales percent: 25% in 2023

Green hydrogen production per year (2023): 1350 tons

Carbon Tax: $ 0

Carbon Trading: $ 61.30, EU Coverage 38%

Renewable projects:

-- Boxberg by LEAG – largest Europa renewable energy hub 7GW

-- Nordlicht offshore windfarm – 980 MW for 2027 Vattenfall

-- Witznitz solar park – 605 MW by HansaInvest

-- BASF Schwarzheide battery recycling plant

-- Eaver-Loop TM ultra-deep geothermal plant in Bavaria

-- Sinn Power vertical floating PV in Bavaria

-- ABB and Vulcan Energy Zero Carbon Lithium project

-- CIBC and BNP plan to built in Ludmin a 100 MW green hydrogen plant

COUNTRY ENERGY TRANSITION STATUS

Iceland – Carbon Neutral: 2040

Electricity: renewable 100% (hydro – 69%, geothermal – 31%)

EV sales percent: 60%

Green hydrogen production per year (2023):

Carbon Tax: US $ 36.51, Coverage: 36%

Carbon Trading: $ 61.30, EU Coverage 38%

Renewable projects:

-- IdunnH2 and IcelandAir plan a green hydrogen facility for 65,000 ton/y SAF near Keflavic Airport by 2027.

-- ORCA 4000 tons CO2/year DAC plant of Climeworks with injection in basalt.

-- Possible large green hydrogen exports to Rotterdam from Landsvirkjun.

-- Nesjavellir CCS plant of Carbfix with injection in basalt.

-- Greenvolt 90 MW wind farm plan.

-- 2 GW offshore wind for exports to UK by cable.

COUNTRY ENERGY TRANSITION STATUS

India – Carbon Neutral: 2070

Electricity: 41.4% renewables, 49.1% coal

EV sales percent: 6.4% in 2023

Green hydrogen production per year (2023): 1500 tons

Carbon Tax: US $ 0

Carbon Trading: under consideration

Renewable projects:

-- Adani Green Renewable Park Khavda, Gujarat – 30 GW

-- Bhadla Solar Park – 2245 MW – Rajasthan – 56 sq km

-- NHPC 2880 MW Dibang Hydropower project

-- Hygenco green ammonia plant in Gopalpur- 1 Mt/y by 2026

-- GAIL green hydrogen plant operating at 1.5 kt/y

COUNTRY ENERGY TRANSITION STATUS

Indonesia – Carbon Neutral: 2060

Electricity: 20% renewables (hydro, geothermal), 61.5% coal

EV sales percent: 6.5%

Green hydrogen production per year (2023): 203 tons

Carbon Tax: US $ 0

Carbon Trading: US $ 0.61, Coverage: 26%

Renewable projects:

-- Gunung Salak – 375 MW geothermal in West Java

-- 145 MW Floating Solar in Cirata reservoir West Java by Masdar

-- Sidrap onshore wind in Southern Sulawesi by Barito Wind

-- Kamojang green hydrogen 4.3 tons/day based on geothermal

-- CCS Hub Java Sea by Pertamina, ExxonMobil and KNOC

COUNTRY ENERGY TRANSITION STATUS

Iran – Carbon Neutral: No Target

Electricity: renewables: 5% (mainly hydro) 94% fossil fuels

EV sales percent: 0%, prohibits import of electric cars

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- 2000 MW Upper Gotvand hydro project in Khuzestan by Iran Water and Power Resources Development

-- 20 MW Mahan Solar PV in Kerman By JAASK Total Development and ARKA Solar Energy

-- 101 MW Manjil and Rudbar wind farm in Gilan

COUNTRY ENERGY TRANSITION STATUS

Iraq – Carbon Neutral: No Target

Electricity: renewables: 5.9% (mainly hydro) 94% fossil fuels

EV sales percent: <1%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- 1 GW Solar plant in Basra by TotalEnergies

-- 300 MW Karbala solar power plant by Scatec

-- 800 tons per year green hydrogen to support refining operations

-- Two windmills on Mount Kweiza near Sulaymaniyah

COUNTRY ENERGY TRANSITION STATUS

Italy – Carbon Neutral: 2050

Electricity: renewables: 42%, natural gas – 49%

EV sales percent: 3%,

Green hydrogen production per year (2023): 4200 tons/y

Carbon Tax: US $ 0

Carbon Trading: $ 61.30, EU Coverage 38%

Renewable projects:

- **1317 MW Entracque pumped storage by ENEL**
- **159 MW Monte Grighini onshore wind by EDF Energia Italia**
- **103 MW Troia solar farm in Apulia by European Energy operating**
- **350 MW solar project in Sicily by Iberdrola**
- **750 MW floating wind offshore Sicily by BayWa r.e.**
- **SoutH2 hydrogen pipeline from North Africa to Germany by SNAM**

COUNTRY ENERGY TRANSITION STATUS

Italy – Carbon Neutral: 2050

(continued):

-- VALLE Peligna green hydrogen project at 4200 tons/y by Axpo and Infinite Green Energy

-- Energy Dome 20 MW/200MWh CO_2 battery in Sardinia

-- ENI Ravenna CCS project

COUNTRY ENERGY TRANSITION STATUS

Japan – Carbon Neutral: 2050

Electricity: renewables 22.7% (2022), LNG – 29.9%, coal- 27.8%

EV sales percent: 3.6% (2023)

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 1.91, Coverage: 80%

Carbon Trading: No

Renewable projects:

-- Setouchi Kerei solar project – 235 MW – 2.6 sq km

-- Ishikari Bay New Port offshore wind farm – 112 MW by JERA

-- 2030 Green H2 Plant, 10 kt/y by ENEOS and Idemitsu Kosan

-- Kawasaki Heavy Industries first liquid H2 carrier Suiso Frontier

-- Hatchobaru Geothermal plant – 112 MW

COUNTRY ENERGY TRANSITION STATUS

Kazakhstan – Carbon Neutral: 2060

Electricity: 13% renewables (hydro), coal – 70%

EV sales percent: 0.02%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: US $ 1.06, Coverage: 47%

Renewable projects:

-- Mangystau Green H2 project – 2Mt/y – Hyrasia and Svevind

-- Mirny 1 GW wind by TotalEnergies with 600 MWh storage

-- ACWA power 1 GW wind

-- Plenitude (ENI) 50 MW solar in Turkistan region

COUNTRY ENERGY TRANSITION STATUS

Kenya – Carbon Neutral: 2050 – 100% renewable power by 2030

Electricity: 86% renewables (hydro, geothermal)

EV sales percent: 8.3%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: under consideration

Carbon Trading: No

Renewable projects:

-- Olkaria geothermal power plant – 322 MW

-- Gitaru hydropower plant – 225 MW

-- Menengai geothermal project – 35 MW by Globeleq

-- 300 MW green ammonia plant by Fortesque Future Industries

-- Possible Climeworks DAC plant removing 1Mt/y CO2

COUNTRY ENERGY TRANSITION STAT

Kuwait – Carbon Neutral: 2060

Electricity: renewables 0.2%, natural gas 65%

EV sales percent: < 0.1%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $0

Carbon Trading: No

Renewable projects:

-- Shagaya CSP, 50 MW with 10 MW solar, 10 MW wind

-- 1100 MW tender for solar in Shagaya

COUNTRY ENERGY TRANSITION STATUS

Mexico – Carbon Neutral: 2050

Electricity: renewables 19.5%, natural gas 56.8% (2022)

EV sales percent: 1.3% (2023)

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 4.31, Coverage: 29%

Carbon Trading: Yes, amount ?, Coverage: 40%

Renewable projects:

-- Cierro Petro geothermal power – 820 MW by CFE

-- Villaneuva solar – Coahuila – 754 MW by Enel Green Power

-- Amistad wind farm – 571 MW by Enel Green Power

-- $ 10 Billion green hydrogen project near Ixtepec by CIP (Copenhagen Infrastructure Partners)

COUNTRY ENERGY TRANSITION STATUS

Morocco – Carbon Neutral: No target

Electricity: renewables 38%, coal 37%

EV sales percent: < 1%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: under consideration

Carbon Trading: No

Renewable projects:

-- Noor Ouarzazate CSP at 580 MW

-- Hevo Green Ammonia Morocco project 183,000 tons/y

-- Tarfaya wind farm 301 MW by ENGIE and ONEE

-- Morocco-UK 3800 km power cable by TAQA and Octopus

COUNTRY ENERGY TRANSITION STATUS

Myanmar – Carbon Neutral: 2050

Electricity: renewables 49% (48% hydro), gas-40%, remainder mainly coal

EV sales percent: 5%? Strong incentives for Evs.

Green hydrogen production per year (2023): 0 tons

Carbon Price: US $ 0

Carbon Trading: No

Renewable projects:

- **790 MW Yeywa Dam hydro project Myitnge River operating**
- **6000 MW Myitsone Dam hydro on Irawaddy River**
- **220 MW Minbu Solar project by GEP**
- **20 MW Taungdaw Gwin solar in Kyaukse by Green Power Energy.**
- **116 MW Minhla onshore wind by NovaWind**
- **360 MW in three wind project by Yunnan Machinery and Equipment in Ann, Gwa and Thandwe.**

COUNTRY ENERGY TRANSITION STATUS

Namibia – Carbon Neutral: 2050

Electricity: renewables 97% (mainly hydro and solar)

EV sales percent: <1%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- Ruacana Hydropower station – 347 MW

-- Mariental Solar project – 45 MW

-- Hyphen green H2 plant – 2 Mt/y ammonia

-- CERIM Luderitz 50 MW wind project

-- Renewables based Oshivela iron plant – 15,000 tons iron/y

COUNTRY ENERGY TRANSITION STATUS

Netherlands – Carbon Neutral: 2050

Electricity: renewables 40% (of which wind 17%), gas 40%

EV sales percent: 25.3%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 71.48

Carbon Trading: $ 61.30, EU Coverage 38%

Renewable projects:

-- 200 MW Shell green hydrogen project in Pernis Refinery, 50 tons/day hydrogen, saves 200,000 tons/y CO2.

-- 500 MWth geothermal energy, goal of Gaia Energy over 25 projects

-- Porthos offshore CCS project, storing 2.5 million tons/y CO2

-- 1 MW Poshydon first offshore green hydrogen project

-- Eemshaven blue hydrogen project by Equinor of 235,000 tons/y

COUNTRY ENERGY TRANSITION STATUS

Netherlands – Carbon Neutral: 2050

(continued):

-- Award of 4 GW of offshore wind in two 2GW projects: to Zeevonk (Vattenfall and CIP) and to SSE Renewables

-- 45-60 MWth geothermal for 13 greenhouse operators

-- 1.5 GW Hollandse Kust Zuid offshore wind by Vattenfall operational

-- 500 MW WindPlan Groen onshore wind in Flevoland

-- 149 MW Dorhout Mees solar park by Solarfields in Flevoland

-- 65 MWh Zeewoude battery electric storage

COUNTRY ENERGY TRANSITION STATUS

Nigeria – Carbon Neutral: 2060

Electricity: renewables 14% (hydro), natural gas – 86%

EV sales percent: 7.1%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- Ashama solar planned project – 200 MW

-- Mambilla hydropower planned project – 3050 MW

-- Katsina wind project – 10 MW

-- FuelCell Energy and Oando 5 MW green hydrogen power

-- World bank mini-grid project

COUNTRY ENERGY TRANSITION STATUS

Norway – Carbon Neutral: 2050

Electricity: renewables 98.2% (hydro and wind)

EV sales percent: 82.4% (2023)

Green hydrogen production per year (2023): 940 tons/y

Carbon Tax: US $ 107.78, Coverage: 65%

Carbon Trading: US $ 61.30, Coverage: EU 38%

Renewable projects:

-- Northern Lights CCS project

-- Hywind Tampen floating wind farm – 88 MW by Equinor

-- Narvik green ammonia project 1000 ton/day by Aker Horizons

-- 2 Torghatten Nord 117-meter hydrogen ferries

-- Svalbard 198kW PV system by Store Norske Energi

-- Greenstat is planning to start the 20 MW, 8 tons H2 per day, Agder plant in Kristiansand

COUNTRY ENERGY TRANSITION STATUS

Oman – Carbon Neutral: 2050

Electricity: renewables - 4% (solar), 96% natural gas

EV sales percent:<1%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- Hydrom 1 Mt/y green hydrogen near Duqm on 1500 sq km

-- Manah 1 Solar project 500 MW by EDF and Kowepo

-- Dhofar Wind Power – 50 MW by Masdar

COUNTRY ENERGY TRANSITION STATUS

Pakistan – Carbon Neutral: 2050

Electricity: renewables - 5%, 35% natural gas, 24% hydro, 15% nuclear

EV sales percent:<1%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: Under consideration

Renewable projects:

-- Oracle green hydrogen plant of 55,000 ton/y in Sindh

-- 100 MW Quaid-e-Azam solar park in Punjab

-- 4320 Dasu Dam hydro project under construction

-- 180 MW Triconboston wind power project

COUNTRY ENERGY TRANSITION STATUS

Peru – Carbon Neutral: 2050

Electricity: renewables - 55% (49% hydro), 35% natural gas

EV sales percent: 0.3%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- Verano Energy green ammonia project in Arequipa for 420,000 ton/y based on 1500 MW solar, to be expanded to 1.65 million ton/y based on 5850 MW

-- 392 MW Huallaga I hydro in Huánuco Region for 2027

-- 300 MW San Martin solar in La Joya by 2025 by Solarpack

-- 260 MW Punta Lomitas wind farm by ENGIE operational

COUNTRY ENERGY TRANSITION STATUS

Philippines – Carbon Neutral: No target

Electricity: renewables - 21% (mainly hydro and geothermal), 62% coal

EV sales percent: 4%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- 150 MW Solar Philippines Concepcion Solar PV Park in Central Luzon

-- 2150 MW Real Wind Power Project in Calabarzon by Highland Infrastructure

-- 150 MW operating Burgos windfarm in Ilocos Norte

-- 650 Nort Samar offshore wind farm project by CIP

-- 1200 MW Bulalacao offshore windfarm project by Blue Circle and others

-- 1024 Calatagan offshore wind project in Calabarzon by ACEN

-- Vena Energy of Singapore is planning to go ahead with 550 MW of solar

COUNTRY ENERGY TRANSITION STATUS

Poland – Carbon Neutral: 2050

Electricity: renewables – 27% (of which wind 14%, solar 8%), coal – 61%,

EV sales percent: 3.6%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0, operators subject to EU ETS are exempt from carbon tax

Carbon Trading: US $ 61.30, Coverage: EU 38%

Renewable projects:

-- Orlen Group hydrogen mobility project, 130,000/y hydrogen in Wloklawek

-- 1560 MW Baltyk I offshore wind by Equinor and Polenergia by 2025

-- 600 MW Polska Solar PV park in Lodz for 2024

-- More than 100 small solar farms in the 1 – 5 MW range

-- Kolo geothermal municipal heating plant

-- 7 km deep geothermal well in Szaflary targeting 150 degrees Celsius

COUNTRY ENERGY TRANSITION STATUS

Russia – Carbon Neutral: 2060

Electricity: renewables – 18% (hydro), natural gas – 46%

EV sales percent: < 2%

Green hydrogen production per year (2023): < 100 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- Bratskaya hydropower in Angara River at Irkutsk – 4500 MW

-- Latgale solar project in Magadan – 400 MW by 2025

-- Novolakskaya wind project in Dagestan – 315 MW by 2026

-- Possible green H2 plant in Sakhalin by Rosatom and LS Group

-- Novatek 200 MW wind project in Yamal LNG (prior to war)

COUNTRY ENERGY TRANSITION STATUS

Saudi Arabia – Carbon Neutral: 2060

Electricity: renewables <1%, natural gas – 67%, oil – 33%

EV sales percent: 5%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- ACWA NEOM project 1.2 Mt/y green ammonia by 2026

-- Dumat AL Jandal wind farm – 400 MW since 2022

-- Al Shuaibah Solar farm at 2060 MW by ACWA by 2025

-- For NEOM 1.67 GW wind power by Envision Energy

-- Possible first ME hydrogen train

COUNTRY ENERGY TRANSITION STATUS

Singapore – Carbon Neutral: 2050

Electricity: renewables – 4.4% , gas - 92%

EV sales percent: 18.1%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 18.48, Coverage: 79%

Carbon Trading: No

Renewable projects:

-- Singapore needs to be a massive importer of renewable energy to achieve the NetZero objective.

-- 43 MW solar plan for Changi airport, mainly rooftop

-- 60 MW floating solar in the Tengeh reservoir

-- Tuas CCS facility using the Equatic process of electrolyzing desalinated seawater, targeting the removal of 110,000 tons CO_2 per year with Boeing carbon credits.

COUNTRY ENERGY TRANSITION STATUS

South Africa – Carbon Neutral: 2050

Electricity: renewables – 7.3% , coal - 80%

EV sales percent: 1.5%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 10.09, Coverage: 82%

Carbon Trading: No

Renewable projects:

- **273 MW Grootfontein Solar project under construction by Scatec**
- **100 MW Kina Solar 1 CSP project operating**
- **147 Roggeveld onshore wind project by Red Rocket near Matjeisfontein**
- **900,00 tons/y green ammonia project in Coega by Itochu and Hive**
- **Boegoebaai Port project of 40 GW for hydrogen by Sasol and Transnet by 2035.**

COUNTRY ENERGY TRANSITION STATUS

South Korea – Carbon Neutral: 2050

Electricity: renewables - 9% , coal - 33%

EV sales percent: 9.3%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- 1200 MW Seamangeum offshore floating solar project behind seawall

-- 1500 MW Haewoori offshore floating wind project off Ulsan by CIP

-- 3200 MW Jindo offshore wind farm cluster by Pacifico Energy Korea

-- 23 MW Garak Market geothermal project in Seoul

-- 250,000 tons per year low-carbon hydrogen plant in Boryeong City

-- 60 MW onshore wind for the Hankuk paper plant

COUNTRY ENERGY TRANSITION STATUS

Spain – Carbon Neutral: 2050

Electricity: renewables – 49.3%, nuclear -20%

EV sales percent: 11%

Green hydrogen production per year (2023): 3000 tons/y

Carbon Tax: US $ 16.12, Coverage: 1.9%

Carbon Trading: US $ 61.30, Coverage: EU 38%

Renewable projects:

-- Puertollano operating green hydrogen plant – 3000 tons/y

-- Teruel wind farm – 760 MW – by CIP and GE Vernova

-- Francisco Pizarro operating solar park – 590 MW by Iberdrola

-- Heineken and ENGIE – 30 MW CSP plant

-- Cepsa - Apical biofuel park – 1Mt/y SAF and green methanol

COUNTRY ENERGY TRANSITION STATUS

Sudan – Carbon Neutral: 2050

Electricity: renewables – 62% (only hydro), 38% oil

EV sales percent: <1%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- 5 MW Al Fashir solar plant operating

-- Plans for 500 MW including 100 MW Dongola project in Northern Sudan

COUNTRY ENERGY TRANSITION STATUS

Sweden – Carbon Neutral: 2045

Electricity: renewables: 63% (45% hydro, 17% wind, 1% solar), 29% nuclear

EV sales percent: 40%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 127.26, Coverage: 40%

Carbon Trading: US $ 61.30, Coverage: EU 38%

Renewable projects:

-- 3400 MW onshore wind in Markbygden 1101 in Norrbotten by Svevind AB

-- 2500 MW Mareld offshore wind farm off Orust Island by Freja Offshore AB

-- 1000 MW Västvind floating offshore wind off Gothenburg by Eolus Vind AB

-- H2 Green Steel plans a 700 MW electrolyser to produce hydrogen and with renewable electricity produce 2.5 Mt of finished steel products in Boden

-- HYBRIT Green Steel has delivered its first green steel to Volvo

COUNTRY ENERGY TRANSITION STATUS

Sweden – Carbon Neutral: 2045

(continued):

-- Biorefinery in Gothenburg by St1 and SCA producing 200,000 tons per year of SAF, renewable diesel and bio based naphtha and LPG.

-- Bothnia Link project by Uniper to deliver in 2027 producing hydrogen for industries and marine transport and e-fuels.

-- Geothermal heating with five 7-km deep wells to provide all heating for Malmö in 2030.

-- Microsoft support for 800,000 tons per year of CO_2 removal by Stockholm Exergi by 2028.

-- 69 MW Solar park in Häshthagen.

COUNTRY ENERGY TRANSITION STATUS

Tanzania – Carbon Neutral: 2050

Electricity: renewables – 32% (31% hydro), locally produced natural gas – 66%,

EV sales percent: <1%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- 2115 MW Morogoro hydropower in Rufiji River by 2024

-- 300 MW Miombo Hewani wind project near Makambako by Windlab Dev.

-- 50 MW Kishapu solar project by TotalEnergies

-- 200 MW Ngozi geothermal project by Tanzania Geothermal Dev Corp

COUNTRY ENERGY TRANSITION STATUS

Thailand – Carbon Neutral: 2050

Electricity: renewables – 18%, natural gas – 65%, coal remainder, no nuclear

EV sales percent: 12%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: 200 Baht (US $ 5.44) planned for 2025 for petroleum products.

Carbon Trading: No

Renewable projects:

-- 45 MW floating solar on Sirindhorn Dam, Ubon Ratchathani

-- EGAT plans in total 2725 MW of hydro-floating solar by 2037.

-- Energy Absolute plans 1200 electric buses in Bangkok

-- Chaiyaphum onshore wind farm project 87 MW of Acciona Energia

-- IBCLNG 25 MW green hydrogen project

COUNTRY ENERGY TRANSITION STATUS

Trinidad and Tobago – Carbon Neutral: 2050

Electricity: renewables – 0%, natural gas – 100%

EV sales percent: <1%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- 112 MW solar by bpTT and Shell operational by 2024

-- Plans to have all ammonia production based on green hydrogen by 2052.

COUNTRY ENERGY TRANSITION

Turkey – Carbon Neutral: 2053

Electricity: renewables – 40% (of which hydro 20%), coals 36%, gas – 21%

EV sales percent: 6.8%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- 288 MW Soma onshore wind in Manisa by Polat Enerji with 4 MWh battery

-- 130 MW Bor-1 Solar PV Park in Nigde by Ecogreen Enerji

-- Bandirma Energy Base for 500 ton/y green hydrogen

-- 80 MW Kizildere geothermal power plant in Denizli

-- 3000 MW Kalyon Karapinar Solar Project by Kalyon

COUNTRY ENERGY TRANSITION

Uganda – Carbon Neutral: 2050

Electricity: renewables – 84% (mainly hydro), bagasse – 8%

EV sales percent: 5%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $0

Carbon Trading: No

Renewable projects:

-- 250 MW Bujagali hydropower operational

-- 600 MW Karuma hydropower project

-- 100 MW Buranga geothermal project by Green Impact Development

-- 20 MW Rupa wind power project by Senok wind Uganda

-- 20 MW Kabulasoke solar plant in Gomba district

-- 200,000 tons/y green ammonia plant at Karuma by IPS and Westgass

COUNTRY ENERGY TRANSITION

Ukraine – Carbon Neutral: 2060

Electricity: renewables – 13% (of which hydro 11%), nuclear – 62%

EV sales percent: 10%

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 0.77/ton, coverage: 32%

Carbon Trading: No

Renewable projects:

-- 246 MW Nikopol Solar Park in the Dnipropetrovsk region operating

-- 565 MW Tyligulska wind power plant in the Mykolaiv region by DTEK Renewables

-- 650 MW wind project near Kharkiv by DTEK Renewables

-- Possible green hydrogen plant in Reni near Odesa initially of 100 MW

-- Possible green hydrogen plant in Zakarpattia initially of 1100 MW

COUNTRY ENERGY TRANSITION STATUS

United Arab Emirates – Carbon Neutral: 2050

Electricity: renewables – 4.5%, fossil fuels – 83%

EV sales percent: 10%

Green hydrogen production per year (2023): 150 tons

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- Al Maktoum – CSP based solar park – 4600 MW in Dubai

-- Al Dhafra solar plant – 2000 MW

-- Hatta pumped Storage – 250 MW – 1500 MWh

-- KEZAD green hydrogen hub – 1.4 Mt/y by 2031

-- Masdar 103 MW wind project

COUNTRY ENERGY TRANSITION STATUS

United Kingdom – Carbon Neutral: 2050

Electricity: renewables – 43%, natural gas – 31% (2023)

EV sales percent: 16.5% (2023)

Green hydrogen production per year (2023): 0 tons

Carbon Tax: US $ 22.62, Coverage: 13%

Carbon Trading: US $ 45.06, Coverage: UK 28%

Renewable projects:

-- Dogger Bank offshore wind – 3600 MW by SSE Renewables

-- Kincardine floating offshore wind – 50 MW by Cobra

-- Dinorwig hydropower in Wales – 1728 MW

-- Shotwick solar park – 72 MW

-- Eden rainforest based on 4.8 km deep geothermal well

COUNTRY ENERGY TRANSITION STATUS

United States – Carbon Neutral: 2050

Electricity: renewables – 21.5%, natural gas – 39.8% (2022)

EV sales percent: 6.5%

Green hydrogen production per year (2023): 15,000 ton(estimate)

Carbon Tax: US $ 0

Carbon Trading: California: US $ 38.59, Coverage: California: 76%

Renewable projects:

-- Green H2 operating plant, 5475 ton/y, Plug Power in Woodbine

-- Hydrogen City, Texas, 0.28Mt/y H2, 2.2GW electrolyser, GHI, 75-mile pipeline to Corpus Christy for 1 Mt/y of green ammonia.

-- Copper Mountain Solar – 802 MW, by Sempra, Boulder City

-- Alta Wind Energy Center, 1548 MW, Kern County, Cal.

-- Coastal Virginia Offshore Wind – 2600 MW

COUNTRY ENERGY TRANSITION STATUS

United States (continued)

-- Edwards Sanborn Solar and Energy Storage – 875 MW with 3,300 MWh of battery energy storage, Mojave Desert, California

-- The Geysers – geothermal complex, 1510 MW, by Capine

-- 1PointFive (Occidental) plans for 70 DAC sites with 1Mt/y storage

-- First H2 Ferry called Sea Change in Bay Area

-- Maryland Bioenergy Center converts 0.12 Mt/y of food waste into renewable natural gas and fertilizer

-- FirstElement Fuels opened first H2 filling station for large trucks

-- NorthStar Clean Energy BECCS project in Michigan

COUNTRY ENERGY TRANSITION STATUS

Uruguay – Carbon Neutral: 2050

Electricity: renewables – 87% (hydro 27%, wind 35%, biomass 22%)

EV sales percent: 1.9%

Green hydrogen production per year (2023):

Carbon Tax: US $ 167.17, Coverage: 4%

Carbon Trading: No

Renewable projects:

-- 1850 MW Salto Grande Binational Hydroelectric Complex (with Argentina)

-- There are 55 wind farms in Uruguay, the largest are: Agua Leguas – 117.5 MW, Pampa – 110.4 MW, Arias – 70 MW, Santa Rita – 70 MW

-- Naranjal Solar PV in Salto – 57.5 MW

-- Green hydrogen plant project in Paysandú producing 100,000 tons of green hydrogen and 180,000 tons of e-gasoline per year in 2026 by Highly Innovative Fuels Global.

COUNTRY ENERGY TRANSITION STATUS

Vietnam – Carbon Neutral: 2050

Electricity: renewables – 42% (of which hydro 29%), coal 46%

EV sales percent: 15%

Green hydrogen production per year (2023): 0 tons/y

Carbon Tax: US $ 0

Carbon Trading: No

Renewable projects:

-- 3500 MW La Gan offshore wind project for 2026 by Asia Petroleum Energy, CIP and Novasia Energy

-- 450 MW Trung Nam Solar PV Park 1 operating

-- 1300 MW Soc Trang wind farm expected in commercial operation in 2024

-- 5000 MW geothermal project to be constructed in Laos for power to Vietnam by the Canadian GEIOS company and WPC of Vietnam

FISCAL SYSTEMS FOR OIL AND GAS

Government Take

In this section dealing with Fiscal Systems often the concept of "Government Take" will be used. It is therefore useful to provide a brief explanation. The Government Take ("GT") is being calculated as follows:

GT = (government revenues/(gross revenues – costs))x 100%

The GT can be calculated for a field. For instance, assume the following: the government revenues from the field are $ 700 million, the gross revenues are $ 2 billion, the capital expenditures are $ 600 million and the operation costs are $ 400 million. In this case the GT is:

GT = (700/ (2000 – 600 – 400)) x 100% = 70%.

FISCAL SYSTEMS FOR OIL AND GAS

Government Take

The GT can be calculated for a field, a contract area or a jurisdiction. It can also be calculated for a part of the cash flow, such as the last 5 years.

Where the government engages in state participation, the government take is usually determined in two parts:

-- the government income take ("GIT"),

-- the government participation take ("GPT"),

-- both together are the total government take ("GTT").

The government take can be determined on an undiscounted cash flow or a discounted cash flow, for instance, discounted at 10%. This results in the Undiscounted Government Total Take ("GTT0") or the 10% Discounted Government Total Take ("GTT10").

FISCAL SYSTEMS FOR OIL AND GAS

Government Take

The GTT0 can be based on a current (nominal, money of the day) cash flow or a constant dollar (real) cash flow.

The GTT0 can be determined for a field that is already discovered, which means the government take is un-risked, or the GTT0 can be calculated for an exploration project. In this case it is called the Risked GTT0. In order to determine the Risked GTT0, two cash flows need to be created: the dry hole cash flow and the discovery cash flow. If there is an 80% probability of a dry hole and 20% probability of a discovery, the two cashflows are combined into a single cash flow; created by adding 80% of the dry hole cash flow to 20% of the discovery cash flow. The Risked GTT0 is than determined based on this single combined cash flow.

FISCAL SYSTEMS FOR OIL AND GAS

Level of Government Take

The level of GTT0 that can be obtained for any prospect or field, depends on the quality of the resource.

The quality depends on:

-- the geology: do we have large prolific reservoirs expected with high well productivities with easy to produce light oil, or are we dealing with small reservoirs with low well productivities and heavy oil,

-- the geological risk: for prospects, the geological risk is very important,

-- the costs: this means the cost of exploring, developing and producing the fields,

FISCAL SYSTEMS FOR OIL AND GAS

Level of Government Take

(continued):

-- the price: for oil this is usually the international oil price, for natural gas it depends on the market conditions,

-- the distance to market: are we dealing with oil or gas located in frontier areas far from the market, with high transport costs, or are the fields within the market area, and

-- "above ground" risk: are we dealing with a country that is associated with high "above ground" risk, such as nationalization risk, balance of payment problems, labor unrest, etc., or is the field located in a country that is considered politically stable (it should be noted, however, that petroleum companies seem to have a remarkable ability to enter high risk countries if the geology is good).

FISCAL SYSTEMS FOR OIL AND GAS

Level of Government Take

The level of government take depends largely on the market forces.

Many governments use licensing rounds whereby the level of government take is a bid item, which can be bid for the highest bonus, royalty, profit share or profit oil/gas share.

Other governments set the government take by legislation, but in that case, it still depends on the market whether petroleum companies want to invest on this basis.

If there is only modest interest in the resource, a simple application system can be used to allow companies that are interested to enter the country. In this case the fiscal system needs to fix the terms.

FISCAL SYSTEMS FOR OIL AND GAS

Level of Government Take – Government Revenue Optimization

Some governments set a specific fiscal system by legislation, applicable to all licence or contract areas.

This does not optimize the government revenues, if there is sufficient interest in the resource, because the fields that are not economic under these terms will not be produced, while at the same time very prolific fields may result in windfall profits.

A better system is to set a relatively low minimum government take and require companies to make competitive bids for each block. In this way the government receives the full market value for each block (assuming there is competitive interest in the blocks). The system can than be further optimized by designing an optimal structure of the fiscal terms as will be discussed later on.

FISCAL SYSTEMS FOR OIL AND GAS

Level of Government Take

If governments apply the recommended optimization strategy for each block, the country will not have a specific government take.

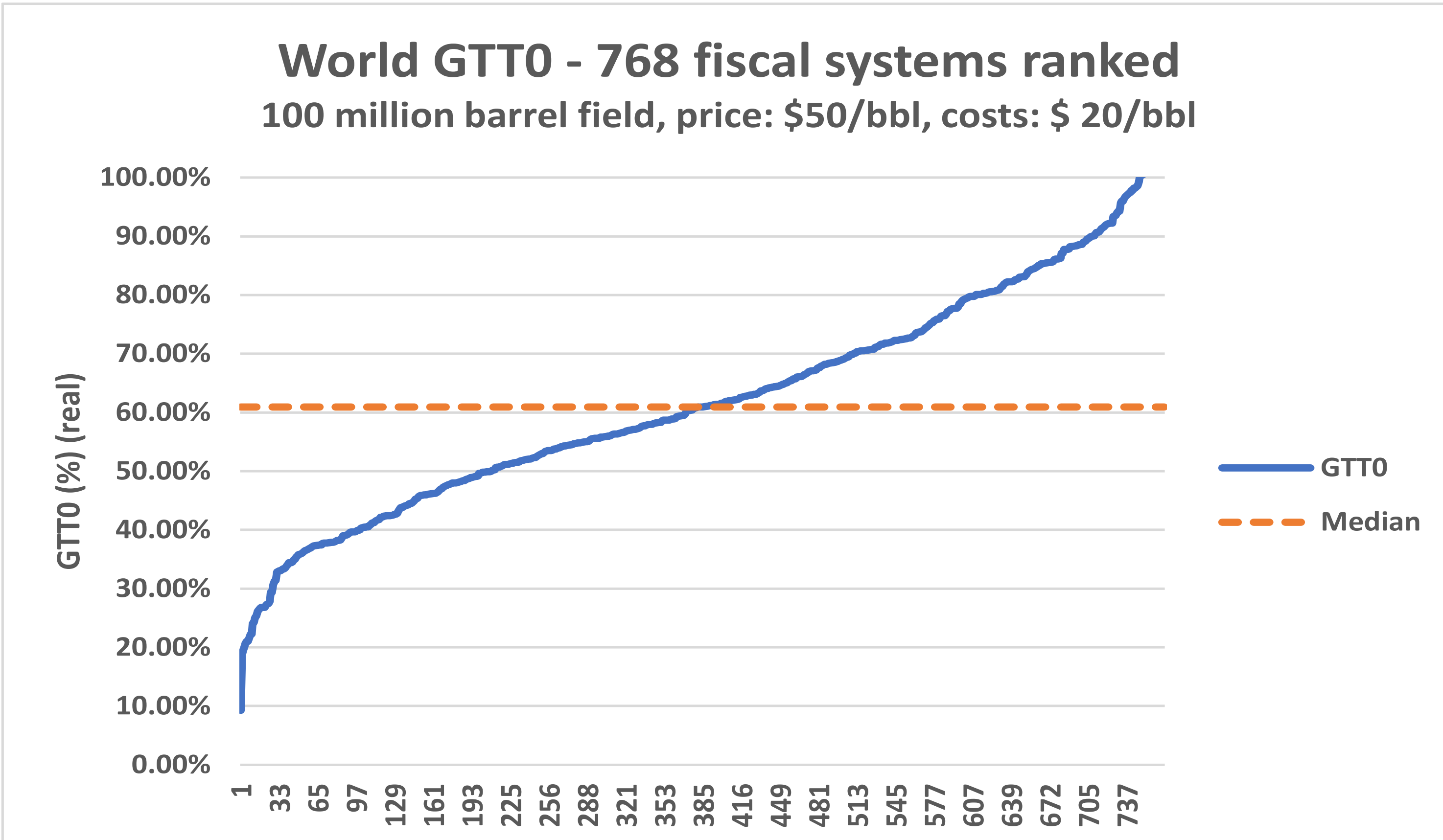
In fact, there could be a wide range of different levels of government take in the same jurisdiction.

Van Meurs Energy keeps track of the levels of government take and therefore there are more "fiscal systems" in the world than governments of jurisdictions. The current data base contains 768 fiscal systems and is being expanded to more than 800.

The following chart shows the range of government takes of these fiscal systems for oil.

FISCAL SYSTEMS FOR OIL AND GAS

Current level of Government Take



The above chart illustrates how the current government takes ranges from a low of 9% to a high of over 100%. The median value for the field size, price and cost level indicated is 60.9%.

FISCAL SYSTEMS FOR OIL AND GAS

Level of Government Take

SAMPLES FROM 768 FISCAL SYSTEMS (100 million barrel field, price: $ 50/bbl, costs:$20/bbl)			
RANK	FISCAL SYSTEM	GTT0	AREA
1	HUNGARY: EOR	9.25%	Onshore
13	PORTUGAL-ON(Gen)	25.05%	Onshore
87	NICARAGUA: General and Equinor (2015)	39.04%	Onshore
174	San Tome & Principe - PSC-Block-12(2016)	47.71%	Shallow Water
240	AUSTRALIA-ON(Queensland)	52.06%	Onshore
321	MOZAMBIQUE: DW(>500)	56.84%	Deep Water
380	NAMIBIA: ON&SW&DW-Pre-1999	60.89%	Onshore
425	PAKISTAN-SW (<200)	62.94%	Shallow Water
501	EGYPT: DW-2016Terms	69.06%	Deep Water
580	ANGOLA-Off(UDWPSC-B46)	75.90%	Deep Water
648	OMAN: Triton PSC (Block 22 - 1996)	83.06%	Shallow Water
702	LIBYA-Oil: ON-EPSA IV - Example #2	89.09%	Onshore
756	IRAQ-MOO-5thRound	103.07%	Onshore
768	IRAN: ON - Buy Back Contract (2002 terms)	200.00%	Onshore

The above chart provides samples from the ranking on the previous slide. It illustrates how a higher government take is associated with fields and blocks that represent a more attractive resource. Iraq and Iran are higher than 100% because these systems relate to resources that are lower costs than $20/bbl.

FISCAL SYSTEMS FOR OIL AND GAS

Future level of Government Take

The future level of government take is primarily determined by the supply and demand for acreage.

Currently, there is a strong interest in supplying new acreage.

The supply of acreage is difficult to predict. Faced with the possibility of a declining petroleum industry, governments may wish to benefit from their remaining petroleum potential by offering acreage.

Much depends on the petroleum industry response to proposed bid rounds. In 2020, 2021 and 2022 the results for governments have not been very positive in several bid rounds.

FISCAL SYSTEMS FOR OIL AND GAS

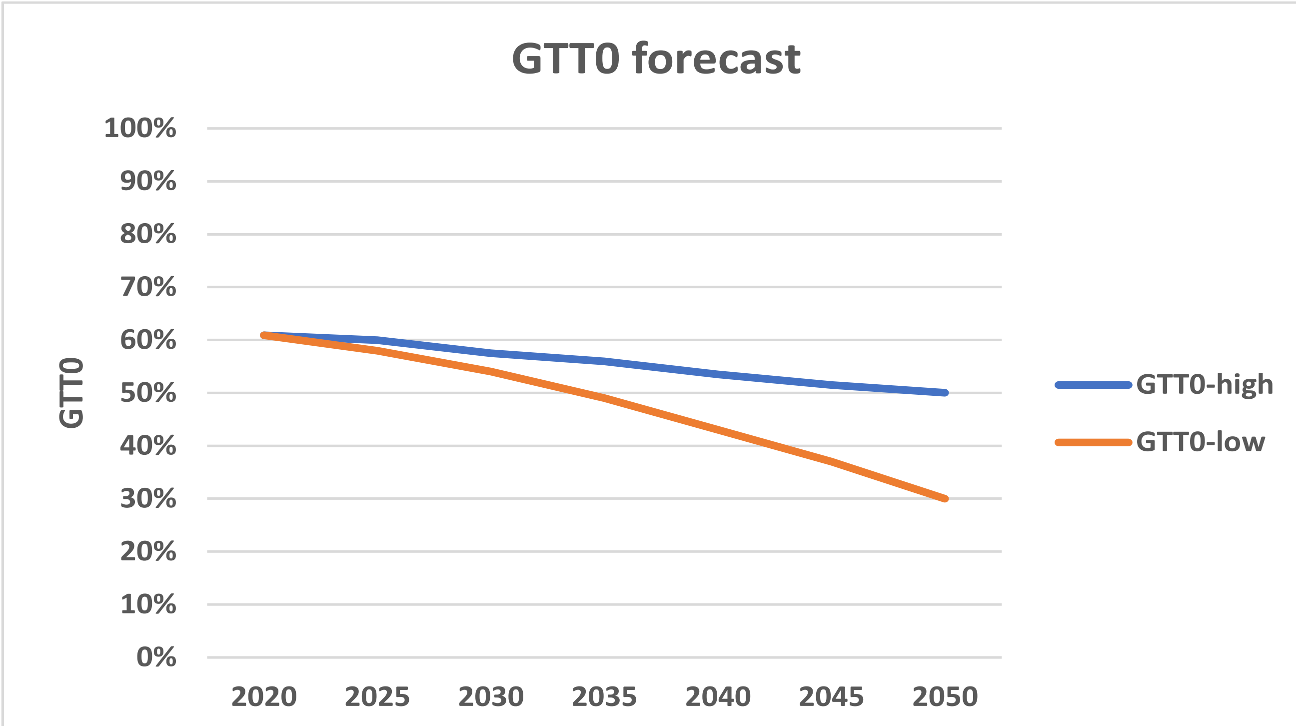
Future level of Government Take

There have been considerable ups and downs in government take since 1974. Van Meurs Energy has over time systematically followed and analyzed these movements. Price movements have always strongly impacted on government take.

Assuming a continued strong interest on the part of governments to offer acreage and less interest by the petroleum industry in development due to lower oil prices, a gradual decline in government take can be expected, possibly from the current 60.9% to about 55% in 2030. For the longer term, the government take may continue to decline slowly. However, if carbon neutrality would be achieved by 2050 the decline will be rapid.

FISCAL SYSTEMS FOR OIL AND GAS

Future of Government Take



The chart provides a projection of the estimated trend of the average government take, declining to about 50% by 2050. However, if nations are successful in achieving carbon neutrality, the decline will accelerate and the average government take may reach 30% or less by 2050, consisting typically of corporate income tax, some other applicable taxes and a low royalty.

FISCAL SYSTEMS FOR OIL AND GAS

Structure of the Fiscal Systems

In the following slides the structure of the fiscal systems will be discussed based on ten different criteria.

The structure of current systems will be illustrated.

The current structure of the fiscal systems of most countries is not adequate to deal with the future petroleum industry framework.

The recommended structure for the future framework will be discussed.

FISCAL SYSTEMS FOR OIL AND GAS

Structure of the Fiscal Systems

FISCAL STRUCTURAL CLASSIFICATION				
Volume/Production Level and GTT0	Regressive	Neutral	Progressive	
Price Level and GTT0	Regressive	Neutral	Progressive	
Cost Level and GTT0	Regressive	Neutral	Progressive	
Profitability and GTT0	Regressive	Neutral	Progressive	
Timing of GTT0	Front End	Neutral	Back End	
Geological Risk and GTT0	Risk Averse	Neutral	Risk Supportive	
Marginal Project Incentive	High	Average	Low	
Cost Efficiency	High	Average	Low	Gold Plating
Price Efficiency	High	Average	Low	Inefficient
MER Efficiency	Enhancing	Average	Inhibiting	Reserve Loss

The above table illustrates the ten criteria with which fiscal systems can be classified.

FISCAL SYSTEMS FOR OIL AND GAS

Analysis of volume, price, cost and profit progressivity

The progressivity of volume, prices and costs can be analyzed by regular sensitivity analysis, as follows:

-- volume sensitivity: doing sensitivity analysis on the size of the field, while keeping the price and costs constant,

-- price sensitivity: doing sensitivity analysis on price, while keeping the size of the field and costs constant,

-- cost sensitivity: doing sensitivity analysis on costs, while keeping the field size and price constant.

-- profit sensitivity: doing sensitivity analysis of profitability, while keeping the field size constant

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Volume/Production Level and GTT0

Based on the size of the field or the production level (and assuming the costs and price stay the same) the GTT0 can be regressive, neutral or progressive, as follows:

-- Regressive: the GTT0 goes down with a higher volume, for instance, the system consists of a large bonus, a fixed royalty and corporate income tax ("CIT"),

-- Neutral: the GTT0 stays the same with a higher volume, for instance a system based only on a CIT,

-- Progressive: the GTT0 goes up with a higher volume, for instance systems with a sliding scale royalty or production sharing based on levels of production

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Price Level and GTT0

Based on the price level (and assuming the costs and field size stay the same) the GTT0 can be regressive, neutral or progressive, as follows:

-- Regressive: the GTT0 goes down with prices, for instance, the system consists of a royalty-tax system,

-- Neutral: the GTT0 stays the same with a higher volume, for instance a system based only on a CIT,

-- Progressive: the GTT0 goes up with a higher prices, for instance systems with a sliding scale royalty based on price.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Cost level and GTT0

Based on the cost level (and assuming the field size and the price level stay the same) the GTT0 can be regressive, neutral or progressive, as follows:

-- Regressive: the GTT0 goes down with lower costs (the system becomes more profitable), for instance, the system consists of a fixed royalty and CIT,

-- Neutral: the GTT0 stays the same with a higher volume, for instance a system based only on a CIT,

-- Progressive: the GTT0 goes up with lower costs, for instance a system with a corporate income tax and uplift.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Profitability and GTT0

Based on the profitability (and assuming the field size stays the same) the GTT0 can be regressive, neutral or progressive, as follows:

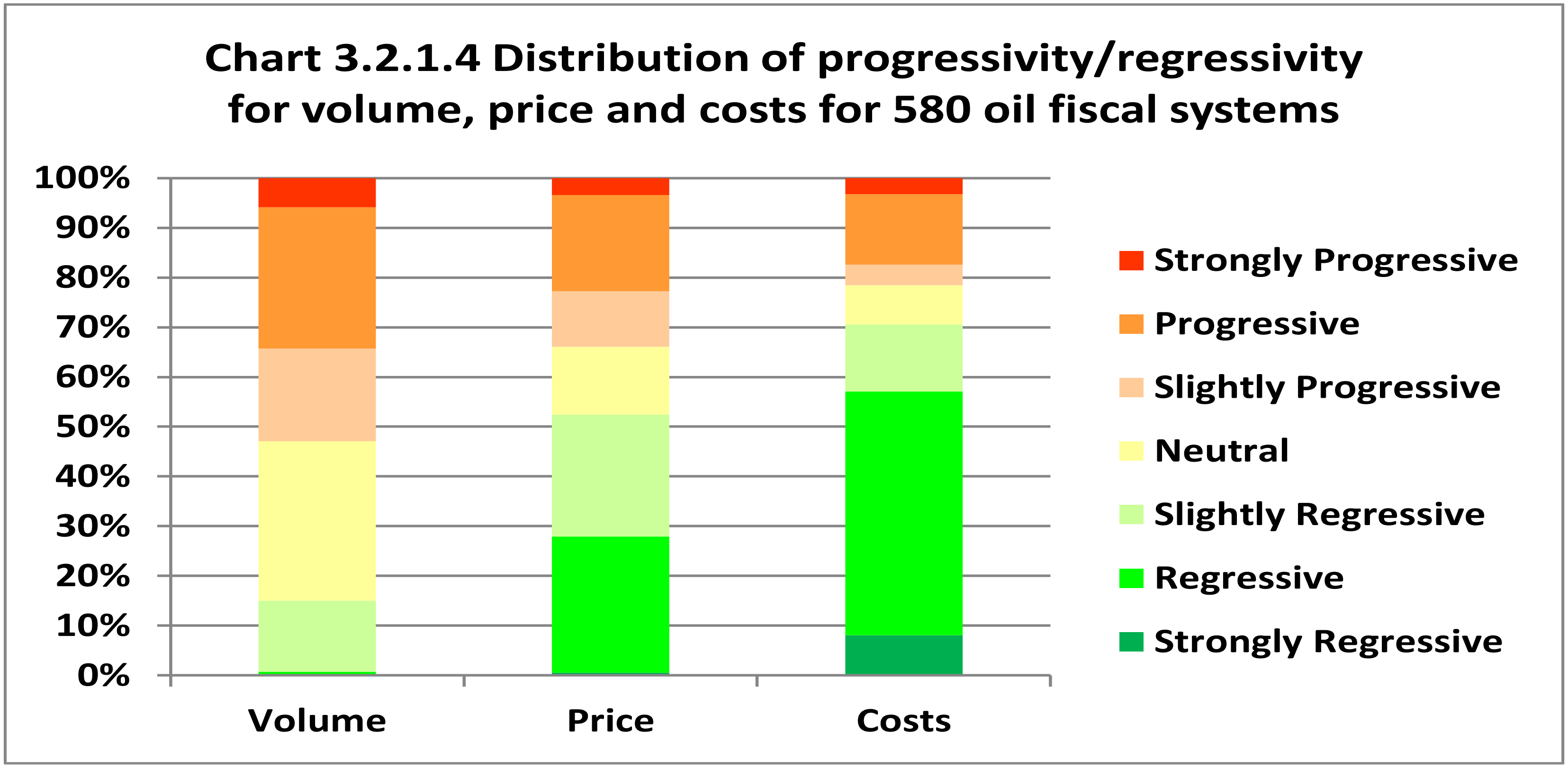
-- Regressive: the GTT0 goes down with higher profitability, for instance, the system consists of a fixed royalty and CIT,

-- Neutral: the GTT0 stays the same with the level of profitability, for instance a system based only on a CIT,

-- Progressive: the GTT0 goes up with higher profitability, for instance a system that varies with profitability; the profit percentage goes up with a higher IRR or R-factor.

FISCAL SYSTEMS FOR OIL AND GAS

Structure of the Fiscal Systems



The above bar charts from the Van Meurs Energy 2012 rating study show the distribution in terms of progressivity/regressivity for 580 fiscal systems in the world based on volume, price and costs. It shows how about half the systems are volume progressive, one third are price progressive and only about 20% are cost progressive (which include profit progressive systems).

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: creation of volume progressivity

Volume progressivity can be created in different ways:

-- the most common way of creating volume progressivity is to provide for royalty sliding scale or profit oil/gas sliding scales based on daily production levels.

-- such scales can also be based on cumulative production levels.

-- other ways are creating special volume-based allowances, for instance for small fields.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Creation of volume progressivity

(continued):

-- The effectiveness of volume progressivity depends on whether there is an economy of scale. Therefore, it is often beneficial to combine volume progressivity with physical factors that indicate profitability.

-- volume progressivity always relates to higher profitability for a system based on well productivity. If two wells are drilled to the same depth in the same area and the well productivity of the first well is higher than the second, the first well is more profitable. Therefore, it is a good system to relate volume progressivity to well productivity (production per well), or do a combination system between total field productivity and well productivity.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Creation of volume progressivity

(continued):

-- In offshore areas water depth is an important indicator of profitability and therefore volume progressive systems can be designed based on water depth.

-- Another factor that impacts on profitability is well depth. Deeper wells are more costly than shallow wells and therefore a volume progressive system could be designed around average well depth.

-- A system based on total field (project) progressivity cannot be recommended for shale oil or shale gas since for these type of resources the economy of scale is weak.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Effects of Volume progressivity

The effects of volume progressivity are the following:

-- Volume progressivity strongly promotes exploration. The attractiveness of exploration is strongly related to field size and in particular the total expected net present value of the field. Most exploration prospects are small fields. Therefore, if a government gives a better deal on small fields it will encourage exploration.

-- There is usually an economy of scale based on field size; larger fields are usually also more profitable. Therefore, a volume progressive system automatically collects a higher rent on larger and more profitable fields. However, this is not always the case and therefore a system that combines volume progressivity with other factors such as well productivity, well depth and/or water depth will be more effective.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Effects of Volume progressivity

(continued):

-- Systems based on daily production levels often create a heavy burden on investors early in the cash flow, since this is the time when production levels are higher, but provides an automatic reduction of burden towards the end of the life of the field when annual operating costs become higher.

-- Systems based on cumulative production have the opposite effect.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal systems: Creation of price progressivity

Creation of price progressivity:

-- price progressivity is usually created through royalty scales based on price, or so-called windfall profit taxes (which are in fact price sensitive royalties). This means the higher the price, the higher the royalty or tax.

-- it could also be created through sliding scales based on price related to other fiscal features, such as profit shares or special profit oil/gas shares over a particular price level.

-- what is an important issue is whether the price levels are adjusted for inflation or not. If price levels are not adjusted for inflation, the burden on investors can become too severe towards the end of a long duration contract, such as a 30-year contract.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal systems: Effects price progressivity

The effects of price progressivity:

-- price progressivity in most fiscal systems is oriented to getting a higher share under high prices, but is not oriented to providing a lower share under low prices. For instance, the system becomes tougher for investors as prices increase over $ 60/bbl, but does not become more attractive to investors below $ 60/bbl.

In other words, the systems are price progressive under high prices but become price regressive under low prices, thereby inhibiting exploration and development under low prices.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal systems: Creation of cost progressivity

Creation of cost progressivity:

-- a simple way to create cost progressivity is to apply a so-called "uplift" which is an extra percentage cost deduction, for instance with an uplift of 30% an investor is allowed to deduct 130% of its cost for tax, profit sharing or profit oil/gas.

-- usually uplifts are applied to capital expenditures only with a goal of encouraging investment, but a few fiscal systems also apply uplifts to operating expenditures (such the Newfoundland offshore terms).

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal systems: Effects cost progressivity

The effects of cost progressivity:

-- as will be discussed under Cost Efficiency, cost progressive systems have to be designed rather conservatively in order to avoid gold plating.

-- However, on this basis, cost progressive systems are an effective way to stimulate high cost petroleum developments and marginal fields,

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal systems: Creation of profit progressivity

Creation of profit progressivity:

-- profit progressivity can be based on total project profitability or yearly profitability.

-- profit progressivity related to project profitability is usually created through a sliding scale based on profitability applied to a tax, profit share, profit oil/gas share or other feature,

-- the project profitability could determined as the IRR or an R-factor; which is a profitability indicator based on a ratio.

-- yearly profit progressivity is based on a ratio based on yearly indicators.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal systems: Creation of profit progressivity

Creation of profit progressivity:

-- project profitability systems have the disadvantage that the burden on investors is high at the end of the project, when the burden should be low in order to extend the life of the field.

-- to solve this problem, Mexico has designed a rather effective combination of a project r-factor with a yearly r-factor for their deep-water blocks.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal systems: Effects profit progressivity

The effects of profit progressivity:

-- as will be discussed under Cost Efficiency and Price Efficiency, profit progressive systems have to be designed rather conservatively in order to avoid gold plating.

-- However, on this basis, profit progressive systems are an effective way to collect windfall profits.

-- It is also an effective way to stimulate high-cost petroleum developments and marginal fields,

-- the systems assist investors to survive periods of low oil and gas prices.

-- However, profit progressive systems applied to small fields strongly discourage exploration.

FISCAL SYSTEMS FOR OIL AND GAS

Analysis of timing, geologic risk and marginal fields

The impact of timing, geological risk and marginal fields can be analyzed as follows:

-- timing: calculating the front end loading index ("FELI"), which is for a particular system and field, the discounted GTT10 (when a 10% discount rate is applied) minus the undiscounted GTT0,

-- geological risk: calculating the government risk sharing index ("GRSI"), which is the Risked GTT0 minus the Un-Risked GTT0,

-- marginal fields: through regular profitability analysis. It can typically be recommended to consider fields marginal if the cost/price ratio is at least 40%.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Timing and GTT0

With respect to the timing and GTT0 three levels can be realized:

-- front end loaded systems: the FELI is a positive number; these systems are created by bonuses, royalties, CIT with low depreciation rates, production sharing contracts with low cost limits. It means governments receive most of their revenues early in the cash flow.

-- neutral systems: the FELI is zero, for instance a CIT with 100% write offs will result in such a system,

-- back end loaded systems: the FELI results in a negative number; these systems are created by profit progressive systems.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Creation of back end loading

The creation of front-end loading and back-end loading is directly determined by the choices of the components of the fiscal system, as indicated in the previous slide.

However, additionally there are other mechanisms to increase back-end loading if this would be the policy. Applying tax credits, uplifts and holidays all promote back-end loading.

For instance, a royalty is typically a front end loaded feature, but by applying a royalty holiday of, for instance, 5 years after the start of production, it can be modified to a back end loaded system.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Creation and front end and back-end loading

In general, it can be recommended that countries with a low social discount rate would apply back-end loading, while countries with a high social discount rate would apply front end loading.

However, the perception of future risk in the petroleum industry is usually an incentive for governments to front end load.

In particular, in the petroleum industry framework developed in this presentation, a policy of strong back-end loading would be a high-risk policy.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Effects of timing of GTT0

Obviously, for a particular level of GTT0 the more a government front end loads the higher the discounted GTT10 will become and the less attractive the fiscal system is for investment.

At the same time, the more attractive and secure the system is for governments. It is therefore that almost all governments in the world have front end loaded systems of various degrees; the UK has a back end loaded system.

There is an important trade off for governments: a less front end loaded system with a higher GTT0 could be just as attractive to investors as a stronger front end loaded system with a lower GTT0. In other words, the government “pays” for front end loading by having to offer a lower GTT0.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Government Risk Sharing

The sharing of geological risk by governments can be classified as follows:

-- Risk Averse: in this case the GRSI is a positive number; a high GRSI is created by ring-fenced systems such as many PSCs.

-- Neutral: in this case the GRSI is zero; a system consisting only of a fully consolidated CIT results in this,

-- Risk Supportive: in this case the GRSI is negative; a system with strong features to promote exploration expenses, such as uplifts on exploration expenses creates such conditions.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Creation of different levels of GSRI

Risk averse systems are created were the GTT0 of the dry hole is less than the GTT0 of the discovery. For instance, if a government has a royalty and a consolidated corporate income tax of say 35%; the GTT0 on the dry hole will be 35%, since the dry hole will be deducted for CIT purposes. However, the GTT0 of the production of the discovery will be higher, for instance 45%. Therefore, the government participates less in the dry hole (in terms of loss of government income) than in the discovery (in terms of gain of government income) and the system becomes risk averse. The strongest risk averse system are where there are ring-fenced PSCs without CIT, or where the CIT of the PSC is also ring-fenced. Another way to create strongly risk-averse system is by requiring high up front signature bonuses.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Creation of different levels of GSRI

Risk supportive systems are created where the GTT0 on the dry hole is higher (in terms of loss of government revenues) than the GTT0 on the discovery (in terms of gain of government revenues). This is for instance the case in South Africa, which has a 100% uplift on exploration expenditures. (Note: the GTT0 is positive on the dry hole because a government loss is divided by a negative project cashflow, creating of negative GRSI).

In general, it can be recommended that countries with a large resource based should have a fiscal system with a low level of GRSI, or even be neutral or risk supportive, since in these countries there will be sufficient discoveries. Countries with a small resource based could be risk averse with a high GRSI.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Effect of different levels of GSRI

The level of the GRSI is the most important factor impacting on the exploration activity.

Most exploration in the world takes place in countries with a relatively low GRSI. All these countries will have consolidated CIT systems that permit the deduction of exploration expenditures for CIT purposes, and sometimes other consolidated taxes or profitsharing systems that permit the deduction of exploration costs.

There is still a considerable number of developing countries that have attractive petroleum potential, but are unable to attract significant exploration as a result of a GSRI that is too high.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Marginal Fields

The incentive to promote marginal fields can be classified based on the analysis of a field with a cost/price ratio of 40% or higher as follows:

-- High (Strong): the IRR (real) is higher than 15% and the PIR10 (real) is higher than 0.15,

-- Average: the IRR (real) is between 10% and 15% and the PIR10 (real) is between 0.00 and 0.15,

-- Low (Weak); the IRR (real) is less than 10% and the PIR10 (real) is negative.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Creation of strong Marginal Fields incentives

The development of marginal fields can be promoted through a variety of ways:

-- generally apply a relatively low GTT0

-- use cost or profit progressive systems,

-- reduce front end loading, through a variety of ways, for instance royalty holidays,

-- where marginal fields are associated with small fields, use volume progressive systems incentivizing small fields, and

-- where marginal fields include non-associated gas fields, use gas-favorable fiscal terms.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Effect of strong Marginal Field incentives

The obvious result of applying strong marginal field incentives is that more marginal fields will be developed.

It should be noted that it are precisely the marginal fields that create employment and business opportunities, due to the high costs of such fields.

Therefore, even if such fields are not major fiscal contributors, they do support economic development in general.

FISCAL SYSTEMS FOR OIL AND GAS

Analysis of Cost, Price and MER Efficiency

The cost, price and Maximum Economic Recovery ("MER") can be analyzed in the following manners:

-- Cost Efficiency: based on the Cost Savings Index ("CSI"), which in turn is analyzed based on differential cost analysis; the Cost Savings Index is the percentage that an investor can keep of the savings achieved as a result of lower costs,

-- Price Efficiency: based on the Price Incentive Index ("PII"), which turn is analyzed based on differential price analysis; the Price Incentive Index is the percentage that an investor can keep of the benefit from obtaining a higher price, and

-- MER Efficiency: based on the MER Efficiency Index ("MEREI"), which in turn is calculated by dividing the GTT0 of the last 5 years of the field life over the GTT0.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Cost Efficiency

The Cost Savings Index can be qualified as follows:

-- High: the CSI is over 50%,

-- Average: the CSI is between 25% and 50%,

-- Low: the CSI is between 0% and 25%, and

-- Gold Plating: the CSI is negative.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Cost Efficiency Creation

The CSI is entirely determined by the choice of fiscal components.

A High CSI is typically created with a system that has important royalties and modest taxes, and could have strong volume or price progressivity; for instance, the US terms in the Gulf of Mexico have a high CSI.

A Low CSI or Golf Plating is created by systems that are excessively cost or profit progressive. For instance, Norway has a low CSI due to the combination of high tax rates and uplifts. Countries that use IRR based scales usually feature Gold Plating or a very low CSI.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Effects of Cost Efficiency

The CSI has a very significant impact on the way petroleum companies operate.

Countries with a high CSI stimulate R&D and development of technology to produce petroleum cheaper and more efficient, because cost savings are significantly rewarded by government.

Countries with a low CSI stimulate the over-declaring costs since the impact of higher costs is largely absorbed by government and therefore over-declaring costs could be profitable.

Countries with Gold Plating in some cases stimulate incurring of excessive and unnecessary costs, since cash flow actually improve in this way.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Price Efficiency

The Price Incentive Index can be qualified as follows:

-- High: the PII is over 40%,

-- Average: the PII is between 20% and 40%,

-- Low: the PII is between 0% and 20%, and

-- Price Inefficiency: the PII is negative.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Price Efficiency Creation

The PII is largely determined by the GTT0. Generally, the higher the GTT0 the lower the PII, since the GTT0 is taken away from the price increase.

A high PII is therefore the automatic result of a low GTT0, while a low PII is the result of a high GTT0.

The PII is, however, furthermore influenced by any price progressive feature. If the price progressive feature is excessive, the PII could become much lower than the GTT0 would indicate, or could even become negative creating a price inefficient system.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Effects of Price Efficiency

Generally, with a high or average PII, the effect on the petroleum industry operations is relatively minor.

Once the PII becomes low or negative, there will be an increased incentive to try to transfer price oil or gas on exports or based on other schemes.

Particularly under a Price Inefficient system, if the company achieves a higher price the cash flow actually goes down. So, the company just as well will try to sell the oil or gas to a foreign subsidiary for an artificially low price.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: MER Efficiency

The MER efficiency can be qualified as follows:

-- MER Enhancing: the MEREI is less than 1.00,

-- Average: the MEREI is 1.00,

-- MER Inhibiting: the MEREI is higher than 1.00, and

-- Reserve Loss: Cash flows indicate an early termination of the field life due to a strong MER Inhibiting fiscal system compared to alternative fiscal terms.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Creation of an MER Enhancing System

An MER Enhancing fiscal system is a system where the burden on the investor is lessened towards the end of the field life. This can be done in a number of ways.

The most common way is through sliding scales based on daily production.

Other system are yearly r-factors, uplifts on operating expenditures, or reduction of tax rates over a level of cumulative reserve recovery (as applied in the Russian mineral extraction tax).

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Creation of an MER Inhibiting System

Systems with fixed royalties are MER Inhibiting.

Profit progressive systems based on project profitability such as the IRR or project R-factor based systems could be strongly MER Inhibiting.

The same applies to price progressive systems that do not adjust for inflation.

Production sharing contracts with a cost limit are also MER inhibiting and could be very strongly inhibiting if the cost limit is low.

Most fiscal systems in the world are MER Inhibiting.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Effects of MER Efficiency

As can be expected, fiscal systems that are strongly MER Inhibiting usually result in reserve and production loss due to early abandonment of the field.

Systems that are MER Enhancing encourage petroleum companies to find ways to increase the recovery factor since it is attractive to do so.

FISCAL SYSTEMS FOR OIL AND GAS

Fiscal Systems: Transformation of Fiscal Systems

In anticipation of a scenario with lower oil and gas prices the current world fiscal systems should be profoundly restructured to optimize the benefit for the various jurisdictions from the remaining oil and gas resources and to maintain a healthy petroleum industry.

This applies to Non-OPEC countries as well as those OPEC countries that aspire to maintain or increase oil and gas production, such as Nigeria and Angola.

In particular, governments should permit more flexibility during licensing round to maximize petroleum revenues and to permit the market forces to decide about the future level of GTT0.

The following slides provide the overview.

FISCAL TERMS FOR OIL AND GAS

Transformation of the Fiscal Systems

TRANSFORMATION OF WORLD FISCAL SYSTEMS		
	CURRENT	FUTURE
Volume Progressivity	The world is mainly volume progressive or neutral	Somewhat more volume progressivity could be introduced
Price Progressivity	About one third of the world is price progressive for high prices, half the world is regressive	Most juridictions should become price progressive at low prices
Cost/Profit Progressivity	About 20% of the jurisdictions is cost/profit progressive and 70% regressive.	More jurisdictions should become modestly cost/profit progressive.
Timing of GTT0	The world is strongly Front End loaded	Front End loading should be reduced in particular in developed countries

The table shows an overview of the required fiscal changes. The most important change is that jurisdictions should increasingly become much more price progressive at low oil and gas prices.

FISCAL TERMS FOR OIL AND GAS

Transformation of the Fiscal Systems

TRANSFORMATION OF WORLD FISCAL SYSTEMS (continued)		
	CURRENT	FUTURE
Geological Risk and GTT0	The world is strongly Risk Averse	Jurisdictions with large resource bases should become considerably less Risk Averse
Marginal Field Incentive	Most countries do not promote strongly marginal fields	Lower prices require that stronger provisions for marginal fields should be introduced
Cost Efficiency	Most systems in the world are cost efficient	Gold Plating should be removed
Price Efficiency	Almost all systems in the world are price efficient	Price Inefficiency should be removed.
MER Efficiency	Many systems In the world inhibit MER	MER enhancement should be significantly expanded

The table shows a further overview of the required fiscal changes. The most important change is jurisdictions with large resource bases should become less risk averse.

FISCAL TERMS FOR OIL AND GAS

Transformation of the Fiscal Systems

TRANSFORMATION OF WORLD FISCAL SYSTEMS (continued)		
	CURRENT	FUTURE
Gas Fiscal favorability	Many jurisdictions have already gas-favorable fiscal systems.	The scope and level of gas-favorability should be significantly expanded
Oil GTT0	The current median world GTT0 at $ 50/bbl, $ 20/bbl costs for a 100 million barrrels field is 61%	Governments should create more flexibility in competitive bid rounds to maximize government revenue collection.

The table shows a further overview of the required fiscal changes. It is important that governments start to apply more flexibility during licensing rounds in order to determine the GTT0 based on market forces, rather than trying to adjust the government take based on pre-conceived ideas of what the government take should be.

FUTURE FISCAL TERMS FOR OIL AND GAS

Transformation of Fiscal Systems - Components

Following is a discussion of the role of the various fiscal components in the fiscal transformation. It is assumed that carbon taxes will apply to the oil and gas burned and vented.

<u>Signature Bonuses:</u> should be eliminated or minimized. However, a secondary role in bid criteria can be useful as will be discussed below.

<u>Surface Rentals:</u> are meaningless amounts in most countries. Some strengthening can be recommended in order to improve acreage management.

<u>Royalties:</u>

-- Main emphasis should be the design of price progressivity under low prices through royalty sliding scales based on price.

-- Price levels should be adjusted for inflation.

FUTURE FISCAL TERMS FOR OIL AND GAS

Transformation of Fiscal Systems - Components

Royalties (continued):

-- royalty sliding scales based on the level of production can be maintained or introduced to enhance exploration.

-- Physical parameters can be introduced, such as water depth, or well depth to make royalties more related to project economics.

--Royalties for gas should be lower than for oil. Royalties could also be lower for unconventional oil/gas and heavy oils.

--Royalty holidays may be introduced to promote marginal fields and/or reduce front end loading.

-- A highly effective way to introduce profit sensitivity royalties, is to base royalties on a cumulative R-factor Mexican style combined with a yearly R-factor.

FUTURE FISCAL TERMS FOR OIL AND GAS

Transformation of Fiscal Systems - Components

(continued):

Corporate Income Tax: Jurisdictions that have currently a ring-fenced CIT should move to a consolidated CIT. Exploration and appraisal expenses should be expensed. Capital allowances based on a long duration of assets should be avoided.

Capital allowances should be permitted when costs are incurred rather than being based on an asset life system.

Surtaxes/Hydrocarbon Taxes: should be considered in a wider range of jurisdictions with a significant resource base. Such taxes should be consolidated. The taxes could have uplifts to make them cost progressive or production allowances to make them volume progressive. Exploration and appraisal costs should be expensed.

FUTURE FISCAL TERMS FOR OIL AND GAS

Transformation of Fiscal Systems - Components

(continued):

Ring-fenced Resource Taxes: Countries with a significant resource base could consider changing to Hydrocarbon Taxes. Otherwise, taxes could be maintained and include uplifts to create cost progressivity or R-factors to create profit progressivity.

Windfall Profits Taxes: should be adjusted to ensure price progressivity at low prices and be lower for gas than for oil and should be adjusted for inflation.

Export duties: should be phased out.

Use of IRR scales: should be phased out. These scales create Gold Plating in almost all countries that feature such scales.

FUTURE FISCAL TERMS FOR OIL AND GAS

Transformation of Fiscal Systems - Components

(continued):

Production Sharing:

-- should include in the PSCs a separate consolidated CIT.

-- Cost oil/gas limits of low percentages should be avoided and be preferably a sliding scale based on price.

-- Profit oil/gas splits should be higher for oil than for gas.

-- Profit oil/gas splits should feature progressive scales based on daily production, price and/or R-factors in order to create progressivity.

-- Uplifts on capital costs can be recommended in order to create cost progressivity inducing a wider range of economic projects.

FUTURE FISCAL TERMS FOR OIL AND GAS

Transformation of Fiscal Systems - Components

(continued):

Use of R-factor scales: are recommended to create profit progressive systems. However, scales should be robust to avoid Gold Plating. The ideal R-factors should be a mixture of project based and yearly based ratios. R-factors should not be based on discounted cash flows.

Price progressive scales: should be adjusted for inflation.

State participation: should be de-emphasized. Jurisdictions should promote renewable resources rather than investing in oil and gas development. State participation in developed countries with a large resource base should feature full sharing of exploration risk, other countries could include carried interest provisions.

FISCAL SYSTEMS FOR OIL AND GAS

Transformation of Fiscal Systems – Bid variables

As indicated earlier, the strategy to maximize petroleum revenues for the government depend very much on a successful bid system whereby prospects or fields are being offered with the widest possible economic characteristics to maximize production.

Furthermore, bid systems should be strictly transparent. This is best achieved with a single bid parameter, either based on a single parameter of a point system that can be self-assessed.

As far as fiscal systems are concerned, royalties, profit shares or profit oil/gas shares are the recommended variables. Governments may set minimums for different blocks in order to avoid an unacceptable low bid for a block. Bonus bids are typically not recommended.

FISCAL SYSTEMS FOR OIL AND GAS

Transformation of Fiscal Systems – Bid variables

However, the recommended variables do not involve an initial outlay. This could result in over-bidding which could be detrimental. Therefore, a pre-established link with a signature bonus could avoid such conditions.

A bid on work commitments in terms of number of wells or work units could be recommended in a variety of circumstances. Basing work commitments on amounts expended cannot be recommended since this does not guarantee the work.

Combinations of fiscal terms and work can be based on a pre-determined point system that can be self-assessed by the bidder, so there is no uncertainty about the amount of points that is creating the winning bid.

PETROLEUM ENERGY ARRANGEMENTS

Introduction

The new petroleum industry framework could merit the creation of new types of petroleum arrangements (licenses, contracts).

It is likely that in a large number of jurisdictions the traditional petroleum licenses or contracts will continue to exist. If petroleum companies want to carry out energy activities related to renewable energy, they would do so under the regulatory regime established for such activities by the Ministry of Energy.

This creates a level playing field for all participants in the renewable energy sector and it would result in the lowest possible costs for renewable energy to the jurisdiction.

PETROLEUM ENERGY ARRANGEMENTS

Introduction

However, there may also be an advantage to a jurisdiction to make use of the attractiveness of the petroleum resources and the desire of certain petroleum companies to diversity to accelerate renewable resource development through the creation of petroleum energy arrangements (“PEA”).

PETROLEUM ENERGY ARRANGEMENTS

Introduction

There is a large number of possibilities. Three concepts will be discussed:

1. **To create a "Limited Scope Upstream PEA" that includes renewable energy activities that are a logical extension of the upstream petroleum activities, and**
2. **To create a "Wide Scope PEA" that is a comprehensive petroleum-renewable energy agreement.**
3. **"Package Deals" whereby a petroleum company undertakes separate petroleum projects and renewable resource projects as a package.**

PETROLEUM ENERGY ARRANGEMENTS

Limited Scope Upstream PEA

Under a Limited Scope PEA, the licensee (or contractor) would have the exclusive right and obligation to produce oil and gas as well as renewable energy and to conduct CCS activities in the contract area.

It should be noted that the production of petroleum typically requires considerable energy, which could be equivalent to 2 – 7% of the total petroleum production.

Therefore, petroleum production results in considerable CO_2 emissions.

PETROLEUM ENERGY ARRANGEMENTS

Limited Scope Upstream PEA-Renewable Energy

The license would require that the licensee shall use to the maximum extend possible renewable energy for energy use in the field.

The licensee would have the exclusive right to produce renewable energy in the contract area or to purchase renewable energy from third parties. If renewable energy is produced in the contract area the licensee shall have the right to sell excess production to third parties. The main objective of this right is to produce renewable energy in the contract area on a scale that is economic. The level would be approved in the field development plan. The third parties could be other petroleum companies operating in the area.

PETROLEUM ENERGY ARRANGEMENTS

Limited Scope Upstream PEA-Renewable Energy

Currently, the obligation or possibility to use renewables for upstream and midstream operations is already considered by many parties.

-- An interesting example is the plan of Novatek to install 200 MW of wind energy based on Vestas turbines to support the Yamal LNG project (prior to war in Ukraine).

-- Another example is Sonatrach which is building a 10 MWp solar plant to supply its oil sites in the Hassi Berkine basin.

-- Ping Petroleum is connecting its Avalon oil field in the UK with floating wind power constructed by Cerulean Winds. It is estimated to remove 20,000 tons of CO2 per year.

PETROLEUM ENERGY ARRANGEMENTS

Limited Scope Upstream PEA-Renewable Energy

-- Equinor has started the Hywind Tampen offshore floating wind project offshore Norway. The wind farm is estimated to provide 35% of the energy requirements of the Gullfaks and Snorre fields, cutting CO2 emissions 200,000 tons per year. When fully completed the wind farm will have 11 turbines with a capacity of 60 MW. It is located in water depth between 260 and 300 meters.

- TotalEnergies will install 15 MW of solar energy in the Lake Albert oil fields in Uganda

PETROLEUM ENERGY ARRANGEMENTS

Limited Scope Upstream PEA-Renewable Energy

Cerulean Winds and Frontier Power are planning to invest $ 25 billion to establish a North Sea wide grid based on three 333 km2 wind power resources to provide green energy to all North Sea platforms that want to connect. The three windfarms will be located 100 km from each other.

Connection will be through High Voltage Alternating Current transmission lines. Excess power will be brought to shore in Scotland through a HVDC line.

Partners in the project are NOV, Siemens Gamesa, Siemens Energy, DEME and Worley.

PETROLEUM ENERGY ARRANGEMENTS

Limited Scope Upstream PEA-Renewable Energy

The type of renewable energy that would be produced depends largely on the geographical conditions.

In offshore areas, it would be primarily wind energy, although also hydrogen based on wind could be produced.

In onshore areas, it would depend on geography and climate, and could be onshore wind, solar PV, solar heat, hydrogen or power and heat based on biomass (where such production does not interfere with agriculture).

If none of the production methods is practical, the renewable energy would have to be purchased. This would imply a Scope 1 plus Scope 2 strategy.

PETROLEUM ENERGY ARRANGEMENTS

Limited Scope Upstream PEA-CCS

The carbon tax applies to any CO_2 emissions, however, where the field development plan requires the CCS of such CO_2, the flue gases shall be injected with a special injection well (or wells) drilled in the contract area into a separate reservoir and the licensee shall have the right to offer CO_2 injection services to other third parties who wish to inject CO_2. Third parties could be other petroleum companies operating in the area.

The amount to be delivered by third parties would depend on the injection capacity of the well or wells.

The injection well would also be used for injection of any possible flaring.

PETROLEUM ENERGY ARRANGEMENTS

Limited Scope Upstream PEA

The obligation for renewable energy production and CCS activities would be stipulated in the license.

The field development plan cannot be implemented unless it is approved by government. The license may set out certain criteria to be applied by government for field development plan approval.

The field development plan approval could be in phases or could be subject to amendments if certain conditions change.

Upon the exhaustion of the petroleum resources in the license area, the licensee should have the option to continue the renewable and CCS operations where that is profitable, sell the operations to other parties or be obliged to abandon the operations.

PETROLEUM ENERGY ARRANGEMENTS

Wide Scope PEA

A Wide Scope PEA would in addition to a Limited Scope Upstream PEA involve significant midstream commitments in term of energy transition and development of renewable energy and access to renewable energy in the country.

It may consist of a package of various licenses consisting of upstream and midstream licenses.

PETROLEUM ENERGY ARRANGEMENTS

Wide Scope PEA

An important possible contribution that petroleum-energy companies can make to the future is in the midstream.

A large problem in the world is that in many developing countries the population simply does not have access to electricity. Without electricity you cannot develop an economy.

The reasons are often related to the complexity of putting integrated electricity delivery systems together, created by the current separation of the petroleum and power industries.

Power plants do not have the capacity to put LNG import schemes together or to create gas pipeline networks. Petroleum companies have no mandate to become independent power producers or power production conditions are uneconomic.

PETROLEUM ENERGY ARRANGEMENTS

Wide Scope PEA – Access to Electricity

COUNTRIES	ACCESS
Burundi	11.0%
Chad	11.8%
Burkina Faso	14.4%
Niger	17.6%
Malawi	18.0%
DRC	19.0%
Liberia	25.9%
Madagascar	25.9%
Sierra Leone	26.1%
South Sudan	28.2%
Guinea Bissao	28.7%
Mozambique	31.1%

COUNTRIES	ACCESS
CAR	32.4%
Rwanda	34.7%
Somalia	35.3%
Tanzania	35.6%
Zambia	39.8%
Zimbabwe	41.0%
Benin	41.5%
Uganda	42.6%
Angola	43.3%
Guinea	44.0%
Mauritania	44.5%
Ethiopia	45.0%

COUNTRIES	ACCESS
Haiti	45.3%
Lesotho	47.0%
Korea,DR	48.5%
Eritrea	49.6%
Mali	50.9%
Togo	51.3%
Namibia	53.9%
Nigeria	56.5%
PNG	59.0%
Sudan	59.8%

The tables show the percentage of the population that has access to electricity. It is based on the "Sustainable Energy for All" ("SE4ALL") data base of the World Bank. The tables show countries where the access is less than 60%.

PETROLEUM ENERGY ARRANGEMENTS

Wide Scope PEA

As can be noted, many of the nations where the population has limited access to electricity have at the same time high quality solar PV, onshore wind possibilities or low-cost biomass.

For instance, Somalia has one of best irradiation conditions and at the same time strong wind conditions along the entire coastline of the country. Nigeria has 427,000 MW of solar potential, in particular in the northern part of the country, which is 42 times the current total installed power capacity in the country.

What is noteworthy is that some of the countries are at the same time OPEC countries, such as Nigeria and Angola, or important (potential) oil and gas producers such as Uganda, South Sudan, Mozambique and PNG.

PETROLEUM ENERGY ARRANGEMENTS

Wide Scope PEA

Already important projects are being undertaken to supply hybrid solar power to towns that are currently not connected to grid.

For instance, the Essor Access to Electricity project contemplates three such projects in the DRC supplying electricity to towns in excess of 100,000 inhabitants, with the goal of supporting 30 such projects.

Hybrid solar projects consist of the supply of solar energy, backup diesel generation, energy storage and local distribution of electricity.

PETROLEUM ENERGY ARRANGEMENTS

Wide Scope PEA

The Wide Scope PEA would be petroleum-energy contracts that would optimize electricity, gas and other energy deliveries to a particular region on the principle that for the coming decades it is likely that the optimization would include natural gas.

The entire system would be optimized under a single arrangement. It could involve purchasing gas from the companies own gas production or from some Limited Scope Upstream PEAs in countries that have attractive natural gas resources. It could involve reduction of gas flaring. It would involve large scale infrastructure for gas development including gas processing plants and gas transportation and distribution networks for delivery to power plants and industries. It could involve LNG imports.

PETROLEUM ENERGY ARRANGEMENTS

Wide Scope PEA

(continued):

The electricity component would optimize the supply of renewable energy from solar PV, CSP, onshore and offshore wind, geothermal, hydropower and power based on biomass.

It would involve the construction of gas power plants in addition to renewable power. It would also involve the transportation and distribution of electricity to individual consumers.

Where economic, it would involve the utility scale storage of electricity.

PETROLEUM ENERGY ARRANGEMENTS

Wide Scope PEA

Obviously, such massive undertakings would involve joint ventures of companies that can put such packages together. Capital requirements would be very large.

Such joint ventures could be combinations of:

-- large petroleum companies and large electricity companies,

-- joint ventures of large petroleum companies that wish to diversify,

-- joint ventures of large petroleum companies that wish to diversify combined with specialized solar and wind companies,

-- or other possible combinations.

PETROLEUM ENERGY ARRANGEMENTS

Wide Scope PEA

The main and serious problem of such undertakings is that it would be massive monopolies in a particular region of the country, even if the regions selected would be relatively small.

For instance, in Nigeria, it are mainly the northern states which do not have sufficient power and the population is large. There could be 20 or 30 PEA's.

The PEA would have to incorporate many of the requirements that otherwise would be separate regulatory requirements, in order to ensure that the entire system "hangs together". In other words, the PEA may override certain laws and regulations and as a result a PEA concept may have to be approved by law.

PETROLEUM ENERGY ARRANGEMENTS

Wide Scope PEA

Because the PEA could practically be a monopoly, the PEA would have to include provisions that would prevent the abuse of monopoly power.

There would have to be provisions for existing power producers and possibly new power producers.

In order to ensure the lowest possible cost of electricity and energy, many of the components of the total project would have to be subject to competitive bidding.

Nevertheless, even under such conditions the monopoly power may be politically unacceptable in some countries or jurisdictions.

PETROLEUM ENERGY ARRANGEMENTS

Inter-mediate Scope PEA

It is also possible to design PEA's that somewhat wider than the Limited Scope PEA.

Majd Olleik, Beirut, Lebanon, suggested such a concept, whereby companies bid a percentage of their revenues from the contractor profit share of petroleum to be re-invested in renewable programs in the country.

This is a very flexible concept and could strongly promote renewable energy, while permitting companies to evolve as energy companies in the country and spread the risk related to energy transition.

PETROLEUM ENERGY ARRANGEMENTS

Package Deals

Any type of package deal is possible. An interesting example is the deal concluded by Total in Iraq in early 2021.

This deal consists of four projects as follows:

1. **To collect and process natural gas from a number of large oil fields,**
2. **To inject seawater in several large oilfields,**
3. **To develop the 200,000 bopd Artawi oil field, and**
4. **To develop 1000 MW of solar energy**

After final negotiations this project is now moving forward with the following participation: Basra Oil Comp – 30%, Qatar Energy – 25%, TotalEnergies – 45%.

PETROLEUM ENERGY ARRANGEMENTS

Package Deals

TotalEnergies and ENI are also doing a package deal in Libya in 2023 as follows:

1. **Boost Waha field oil production by 100,000 bopd,**
2. **Raise production Mabruk field, and**
3. **To develop 500 MW of solar energy**

THANK YOU