

BOOK 7

Renewables

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TPA

Sharing Experience

Building bridges between the oil industry and academic circles by delivering technical or business-related presentations by professors or experts.



OIL & GAS and ENERGY GLOBAL ISSUES

A Toolbox to understand the World of Energy in the Global Economy

The Toolbox is updated twice a year and benefits from the contributions of TPA Professors:

Coordination: GUÉRITTE Christian

LUC Benoît, PERSILLON Philippe, CORDIER Jean-Pierre, PAPÉE Jean, MULLER Isabelle, DEUTSCH Denis, FOURCADE Bernard, MICHAUD Olivier, SAINCRY Daniel, FOURNIÉ François, CHOUX Jean-Claude, BERA Jean, GUYS Philippe, DE MERVILLE Eric, DUMAY Jean-Michel, VALDELIÈVRE Michel, FONTAINE Jean-Marc, FERRIER Jérôme, BITEAU Jean-Jacques, PETTEAU Pascal, NOSJEAN Nicolas



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2. Wind Energy

3. Solar Energy

4. Biomass Energy

5. Geothermal Energy

6. Marine Energy





Global Remarks on Renewable Energy Sources



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11. Dismantlement/End Life Equipment Recycling



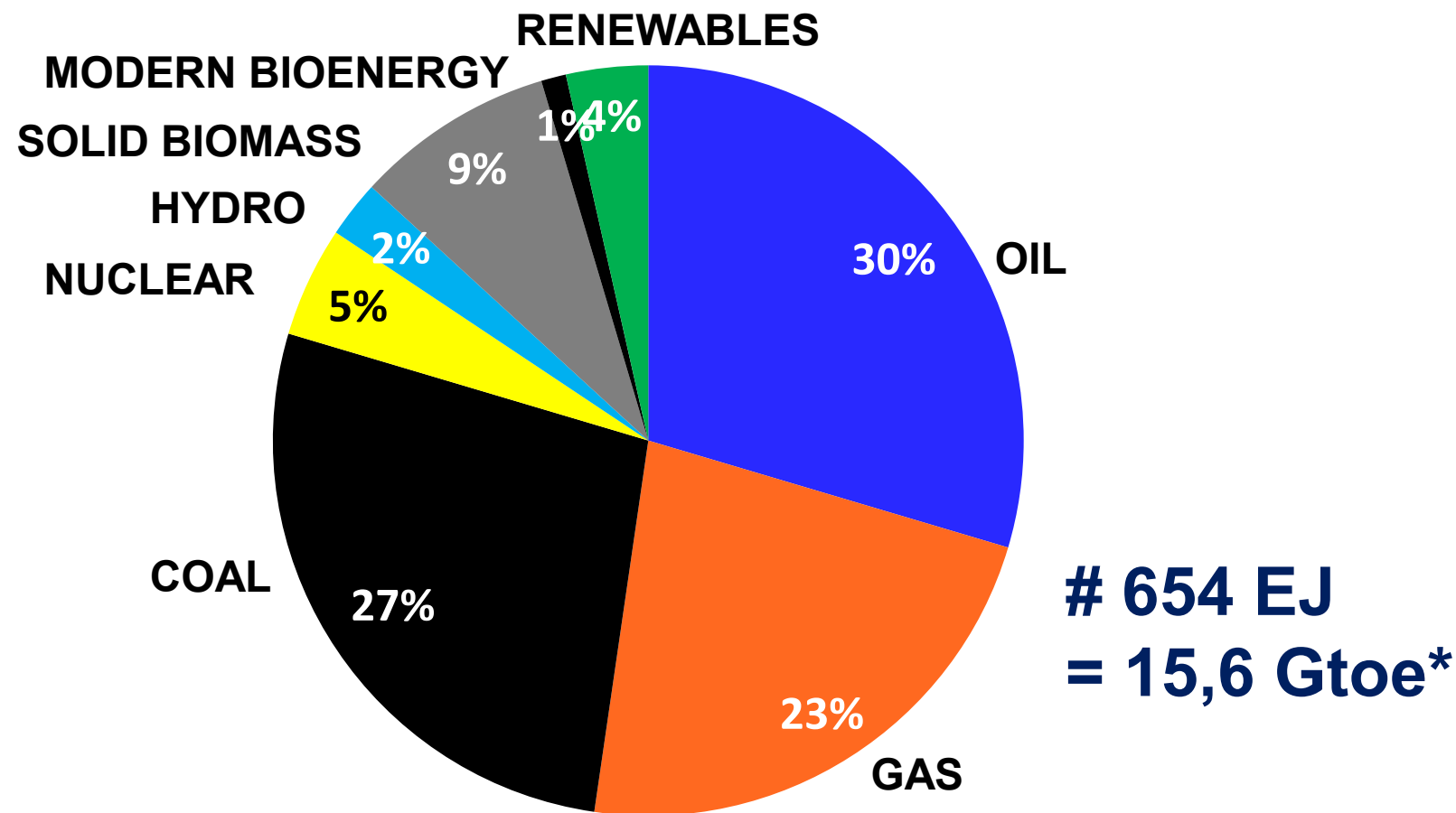
1-1

Renewables in the Energy Mix



World Primary Energy Demand – 2024

+ 2,0% vs 2023



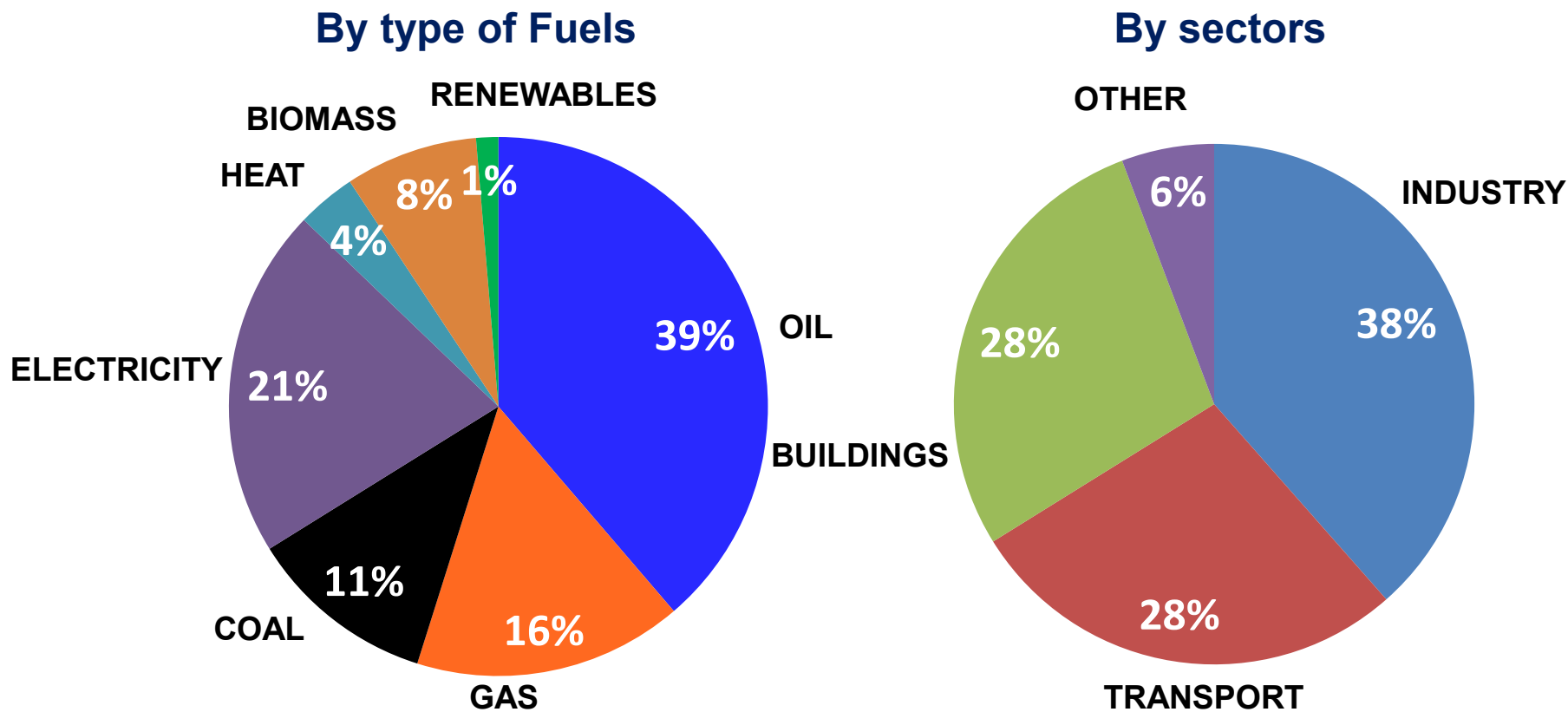
* out of which electricity generation # 6,5 Gtoe # 31 100TWh (eq. Primary Energy)

Source: Data from IEA WEO 2025. Nota: Sums might not be equal to 100% due to rounding

Solid Biomass: tradit. wood & charcoal & solid residues. Modern Bioenergy: liquid & gaseous bioenergy (biofuels & biogases) Renewables: Solar, Wind, Geothermal, Marine Energy,...



Total Final Consumption – 2024 + 2,0% vs 2023



453 EJ = 10,8 Gtoe

Nota: Sums might not be equal to 100% due to rounding
OTHER relates to agricultural sector & other non-energy use

Source: Data from IEA WEO 2025



Renewable Energy sources in the World Primary Energy Production

different statistical concepts

Total world Primary Energy

15,6 Gtoe

2,4

16%

62%

16%

23%

VS

Commercial world Primary Energy

14,1 Gtoe

1,1

8%

15%

35%

50%

Renewables
(Gtoe)

Renewables (%)

Biomass/Bioenergy

Hydro

Others

Commercial Primary Energy excludes traditional use of biomass
& includes modern liquid and gaseous bioenergy

12

January 2026 Climate change - Energy transition

Published figures need a correct understanding: Installed Power vs Delivered Energy

90% of published figures are MW (installed power) while 10% are MWh (delivered energy). Different concepts for Availability or Capacity factor

Average time percentage of electricity production equivalent to the installed nominal power:

◆ Availability Rules of thumb (*)

■ Fossil – Biomass	80-90%
■ Nuclear	80-90%
■ Geothermal	85-95%
■ Hydroelectricity	35-40%
■ Wind offshore	30-40%
■ Wind onshore	25-30%
■ Solar	15-25%
■ Marine	variable

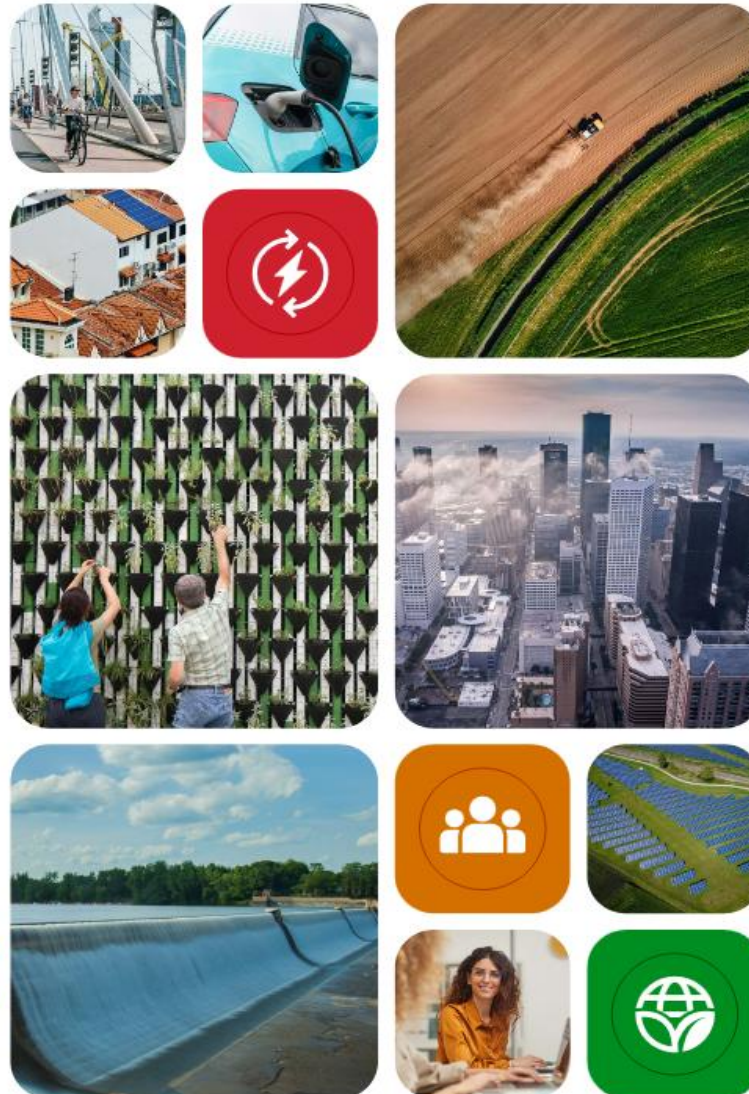
Energy = Power x Time
Energy expressed in Wh (Watthour)
Power expressed in W (Watt)
1 W → x24 hoursx365 days = 8760 Wh/year

(*) with limitation on availability only (i.e. without taking into account demand fluctuations)

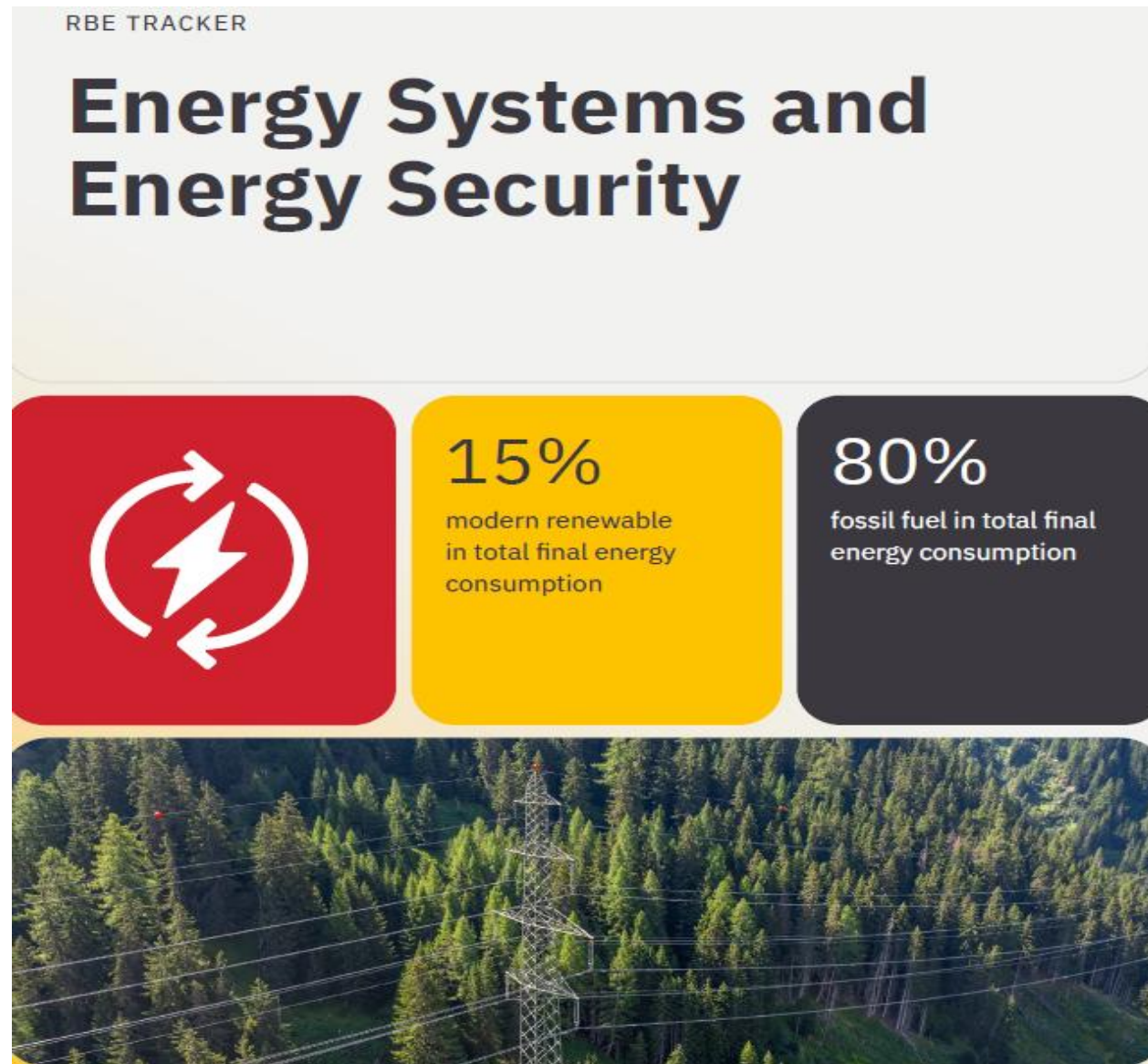
Nota: Availability/Capacity Factor must not be confused with installation efficiency ratio.



REN21 Global overview



REN 21 Global Overview 2025

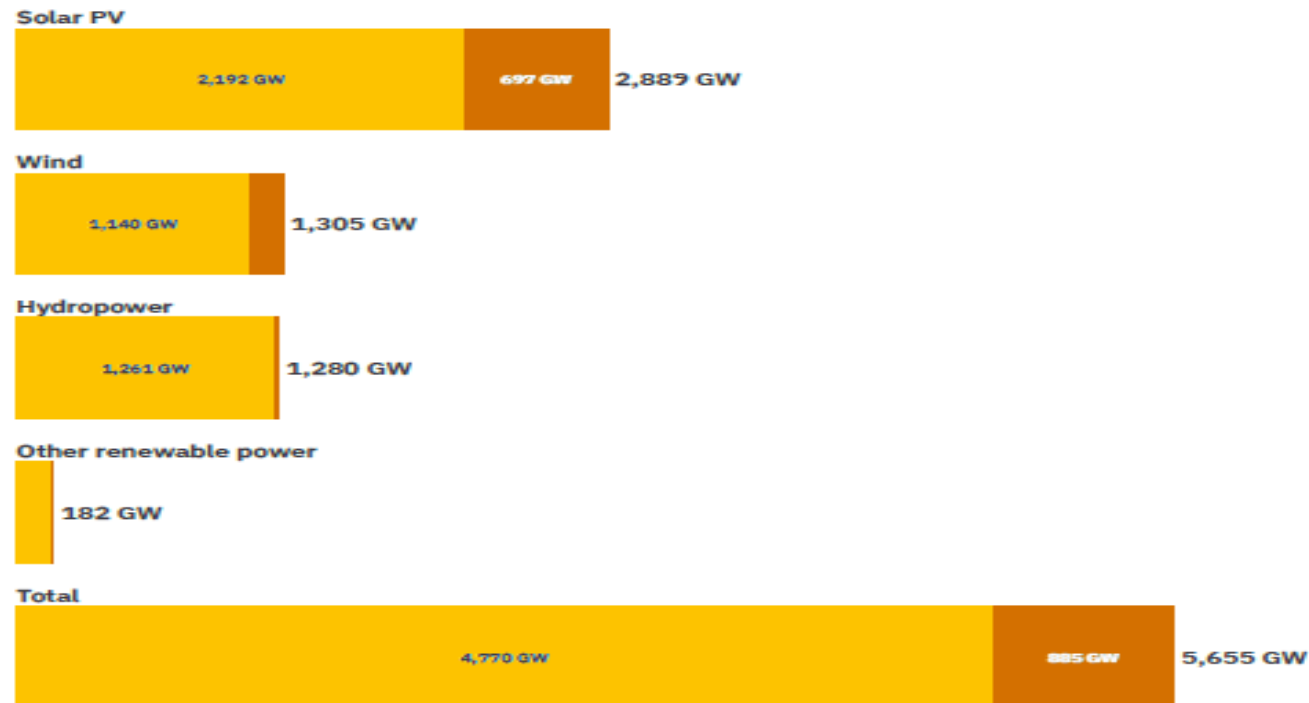


REN 21 Global Overview 2025

Global Renewable Power Capacity and Annual Additions, by Technology, 2025

Solar PV dominates new capacity additions by a wide margin, while wind continues to expand and hydropower growth remains comparatively limited, reinforcing a shift toward faster-deploying technologies

● 2024 total ● 2025 additions



Source: IEA-PVPS, 2026, GWEC, 2026, IRENA, 2026 - CSP Guru, 2026 (personal communication)²⁸

Note: Data for 2025 are compiled from multiple technology-specific sources. Solar PV additions and total capacity are based on direct current (DC) values. "Other renewable power" includes concentrated solar thermal power (CSP), bio-power, geothermal and ocean power. CSP additions are based on personal communication, indicating around 900 MW of new CSP capacity additions in China in 2025. Bio-power additions of 3.25 GW and geothermal additions of 259 MW are based on the cited IRENA data. No new ocean power capacity additions were identified for 2025. Total renewable power capacity additions for 2025 therefore amount to around 885 GW, bringing cumulative global renewable power capacity to around 5655 GW by the end of 2025.

REN21

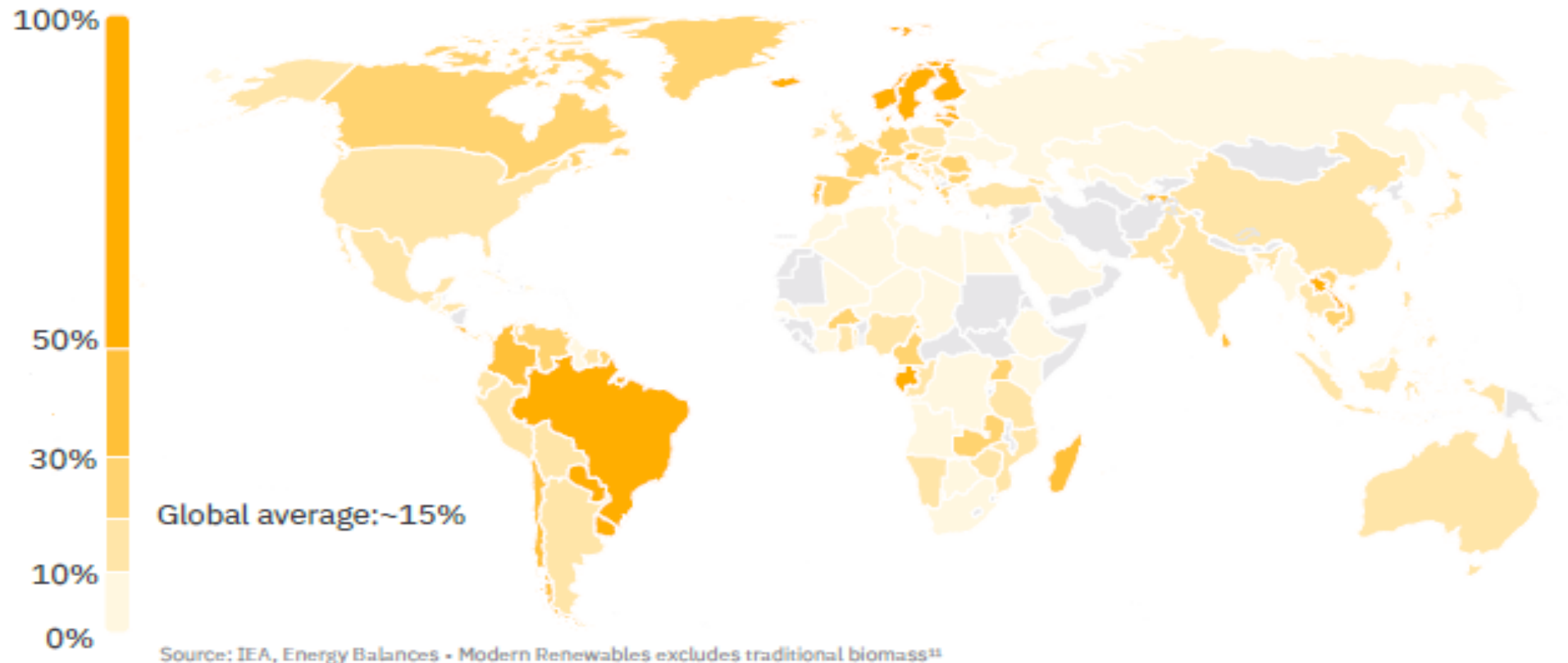


REN 21 Global Overview 2025

Renewable share of Final Energy Consumption

Renewable Energy Share in Total Final Energy Consumption, by Country, 2023

Renewable energy uptake remains uneven across countries, with most economies still below 20% of final energy use and significant disparities in progress toward system-wide transformation

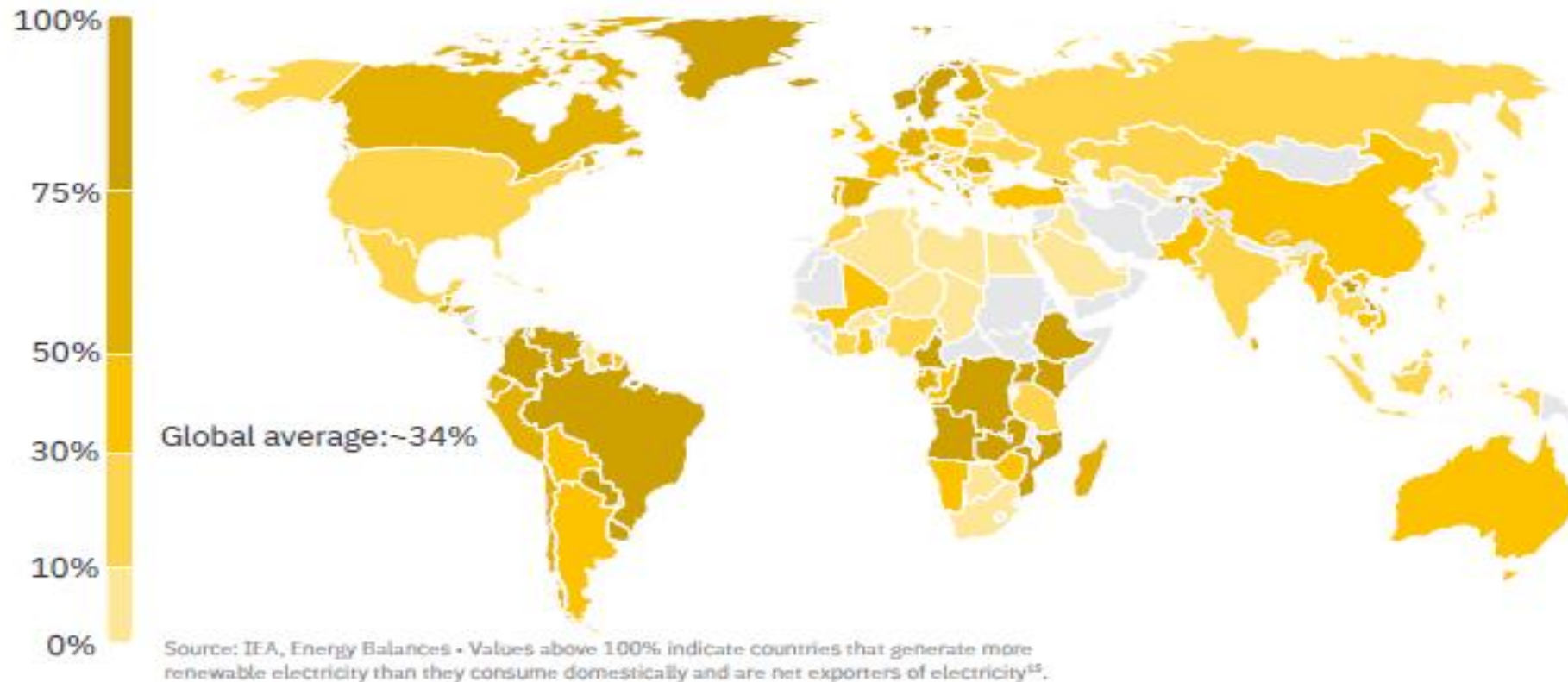


REN 21 Global Overview 2025

Renewable share of Electricity Generation

Renewable Energy Share in Electricity Generation, by Country, 2024

Renewables are rapidly expanding in the power sector across most regions, providing a strong foundation for broader energy system transformation



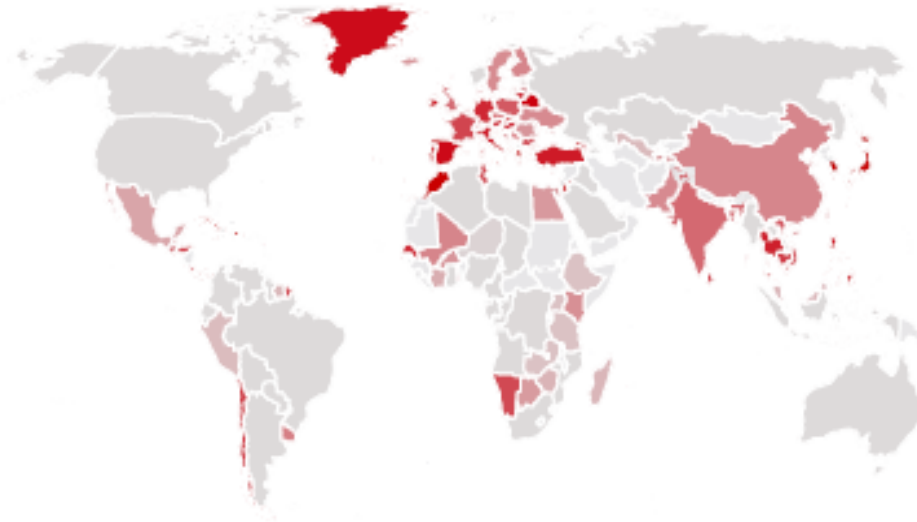
REN 21 Global Overview 2025

Net Energy Importers & Exporters

Net Energy Importers and Exporters, by Country, 2023

Of the countries covered, most countries remain net energy importers: 92 countries import more energy than they produce, compared with only 36 net exporters.

Net Imports (% TFEC)



Net Exports (% TFEC)



Source: IEA, 2026¹⁷.

Note: Please note that some countries are lacking comprehensive energy imports and export data.

REN 21 Global Overview 2025

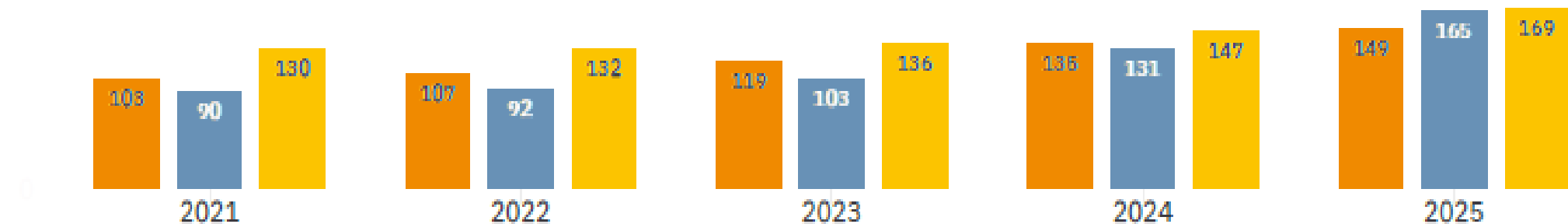
Global Investments in Power Grids by Regions

Global Annual Investment in Power Grids, by Region, 2021-2025

Grid investment rose from USD 323 billion in 2021 to USD 483 billion in 2025, with the fastest growth occurring in Europe, the Middle East and Africa

● Americas ● Europe, Middle East & Africa ● Asia Pacific

USD billion



Source: BloombergNEF, 2026²⁸

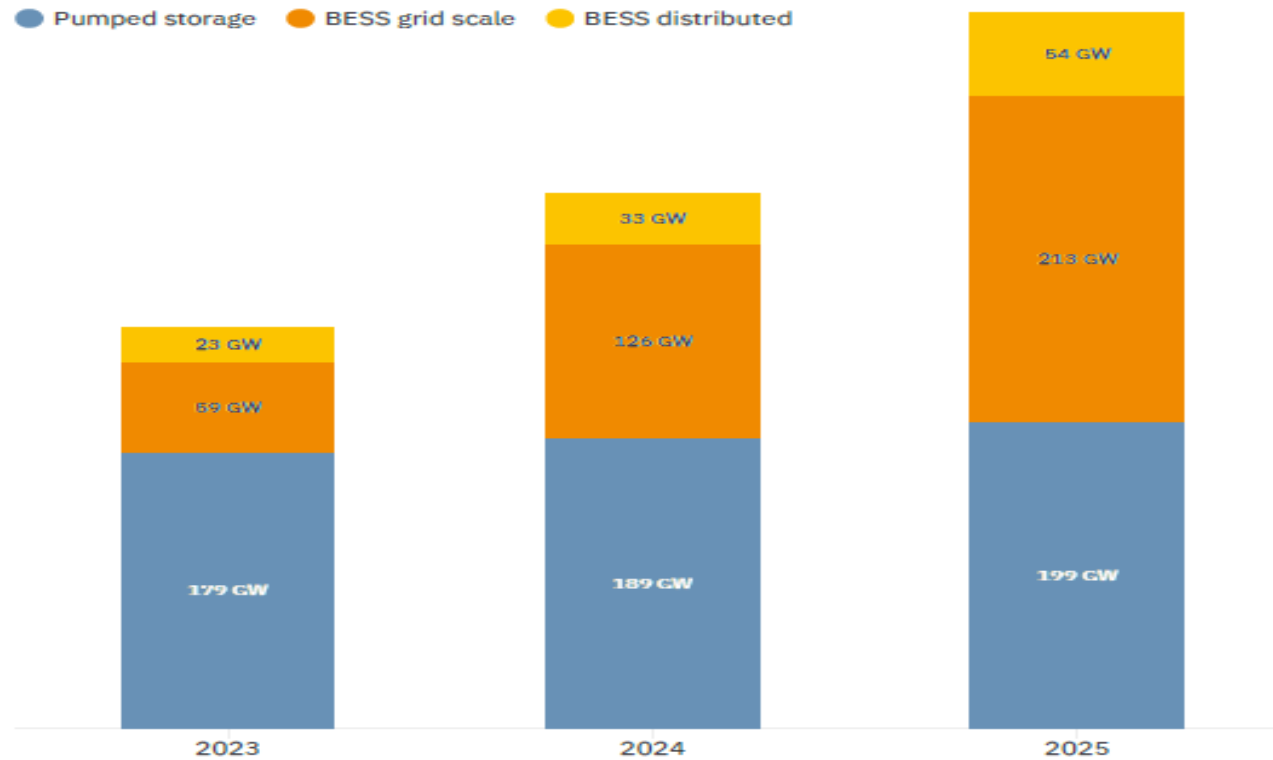


REN 21 Global Overview 2025

Energy Storage – Global Installed Capacity by Type

Stationary Energy Storage, Global Installed Capacity, 2023, 2024 and 2025

Utility-scale battery storage remains the fastest growing technology and surpassed pumped storage in 2025



Source: IEA, 2026, Volta Foundation, 2025, Energy Institute, 2025 - IHA, 2024 (personal communication) IRENA, 2026²³
 Note: Pumped storage data for 2023 and 2024 are based on personal communication between the International Hydropower Association and REN21. Pumped storage data for 2025 are derived from the cited IRENA data.



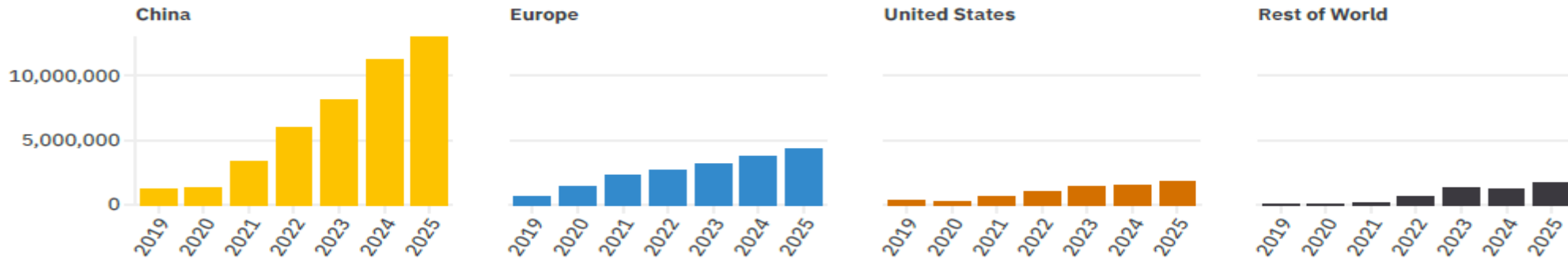
REN 21 Global Overview 2025

Electric Vehicles Sales

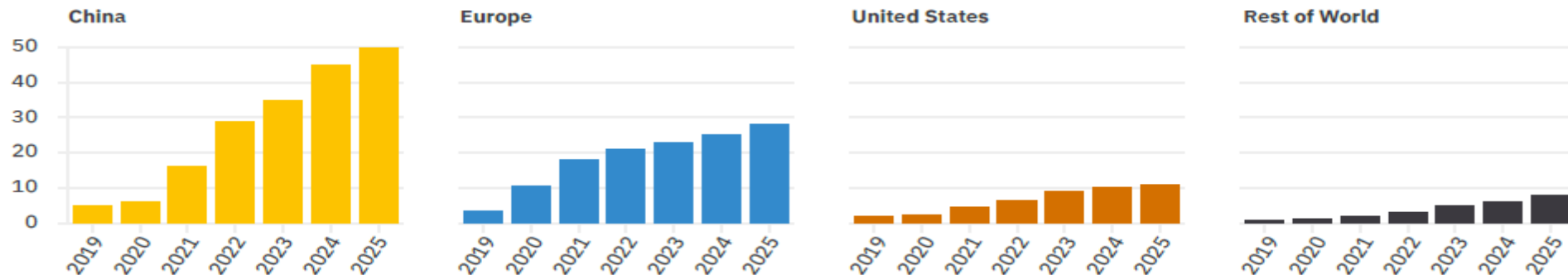
Electric Vehicle Share of New Car Sales, by Region, 2019–2025

Electric car adoption is expanding across all regions, with EVs exceeding 25% of global new car sales in 2025

Total global sales



% Share of new car sales



Source: IEA, 2026³⁸

REN21

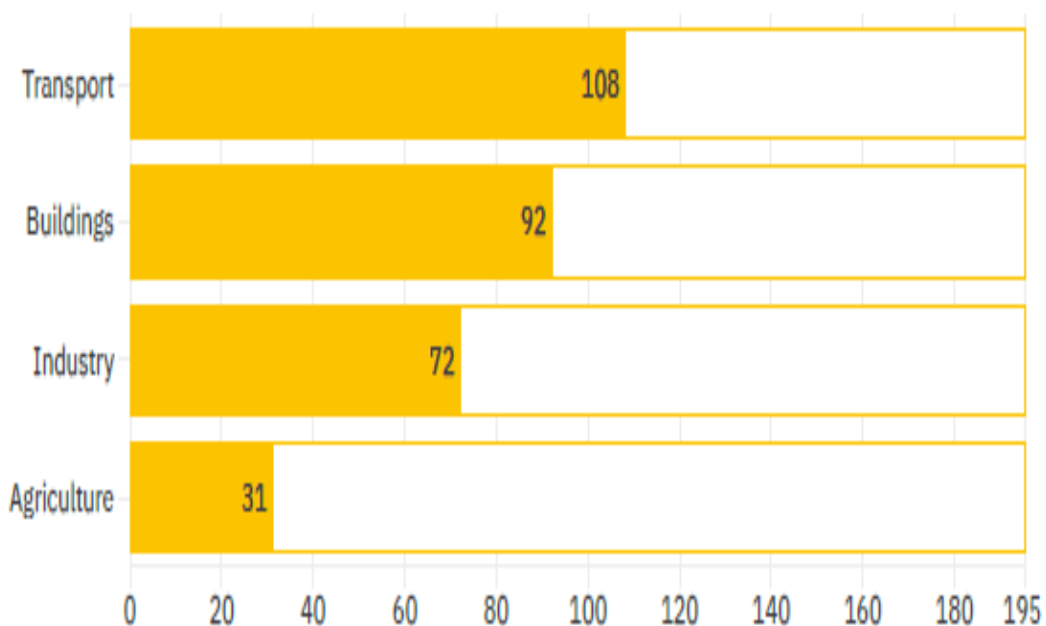


REN 21 Global Overview 2025

Countries with Energy Transition Policies

Countries with Policies for Energy Demand Sectors, per Sector, as of 2025

Number of countries with policies



Source: REN21 Policy Database, 2026⁶⁴.

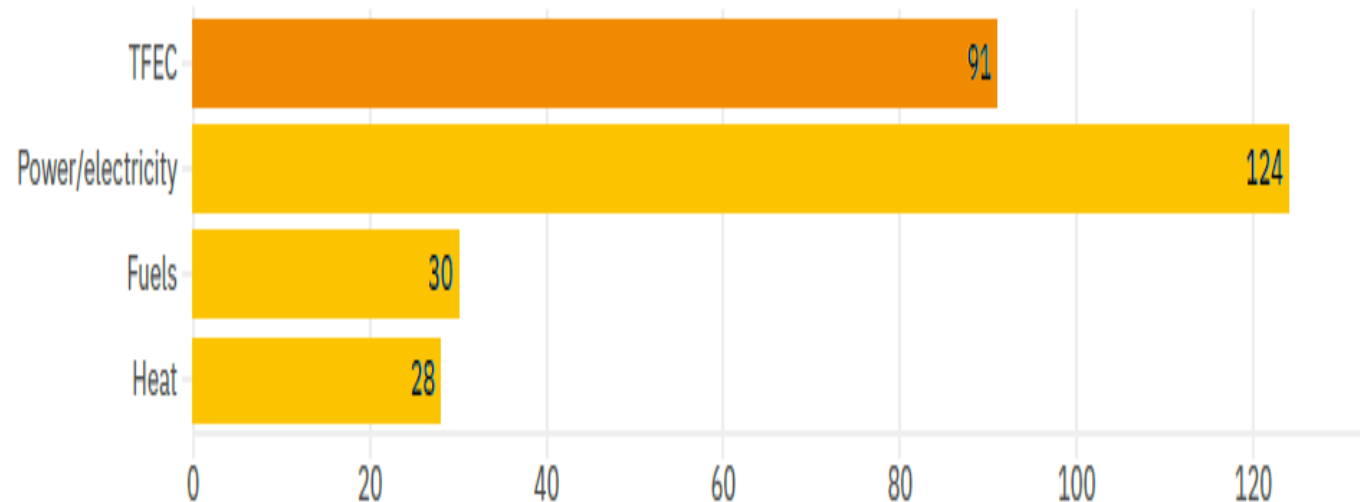
195 countries including 193 UN member states and two observer states are considered.



Countries with Targets for Renewable Energy Share, as of 2025

Renewable energy targets are most common in the power sector, while targets for renewable heat and fuels remain far less widespread

Number of countries with targets



Source: REN21 Policy Database, 2026⁶⁷.

Note: From 195 countries including 193 UN member states and two observer states. Targets for capacity or generation that do not mention a share of final consumption or generation are not included. For fuels, targets include biofuel blends if expressed as share of total content. Due to changes in the methodology, the figure cannot be compared to previous publications from REN21.

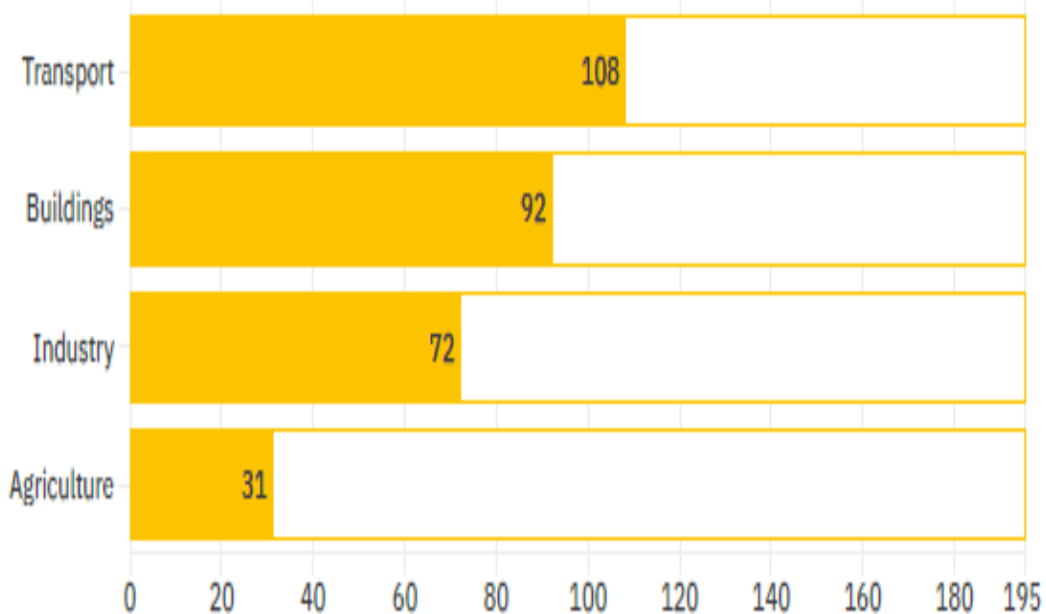


REN 21 Global Overview 2025

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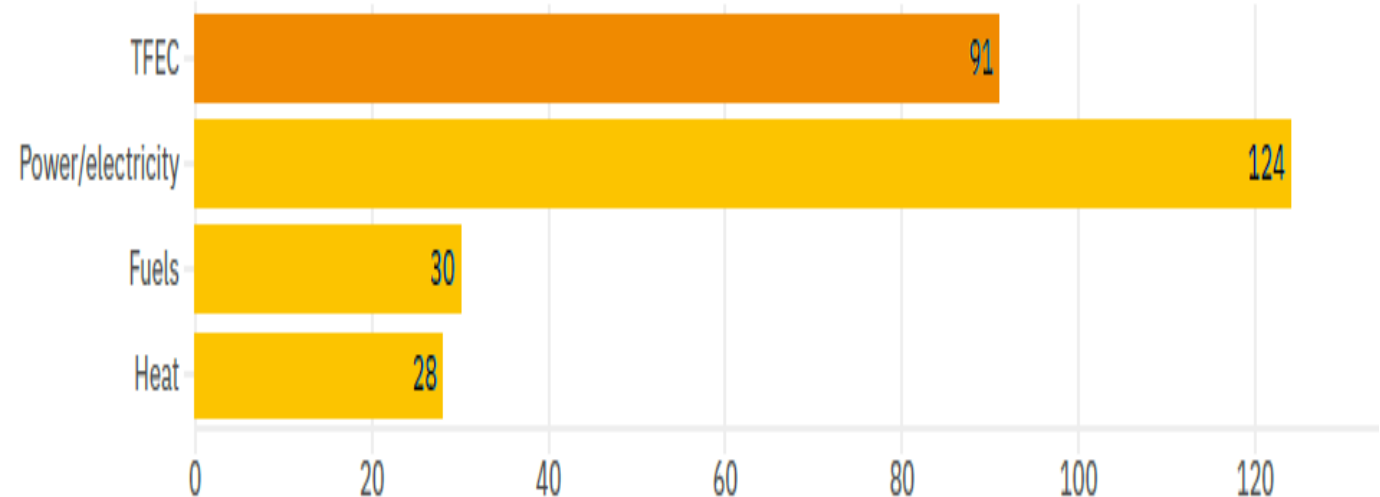
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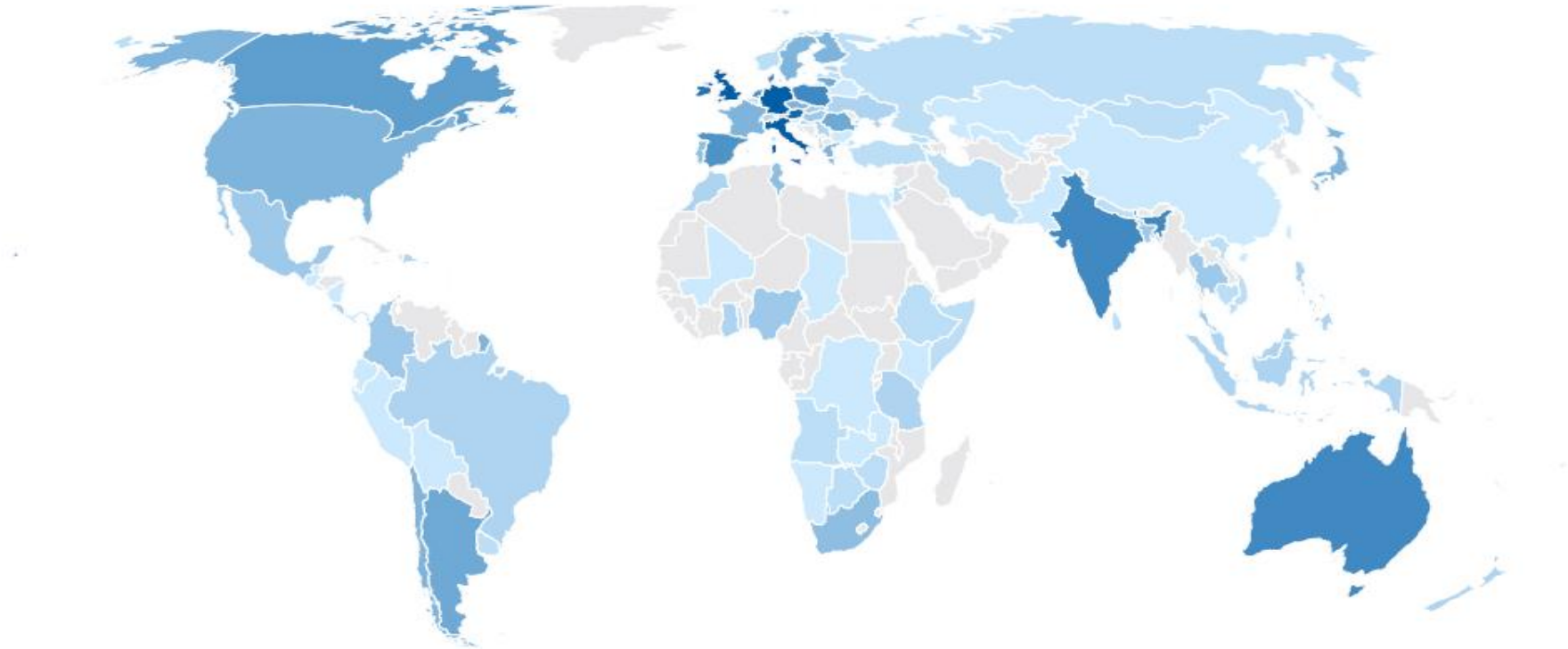
REN 21 Global Overview 2025

Countries with Fiscal & Financial Policies in favor of Renewable Energy

Fiscal and Financial Policies for Renewable Energy, by Country, as of 2026

114 countries have fiscal or financial support measures for renewable energy in place

Number of policies per country 1 14



Source: REN21 Policy Database, 2026⁹⁴

Note: Policies reflected in this map refer to fiscal and financial policies that explicitly support renewable energy. EU-level policies are not reflected. US policy tracking may be incomplete or inaccurate; the current federal administration has rolled back elements of the Inflation Reduction Act, and the status of individual policies, whether fully cancelled, partially rescinded, or still being applied, remains uncertain. China's low policy count reflects the deliberate phase-out of fiscal support instruments as the country's renewable energy market has matured.

REN21



REN 21 Global Overview 2025

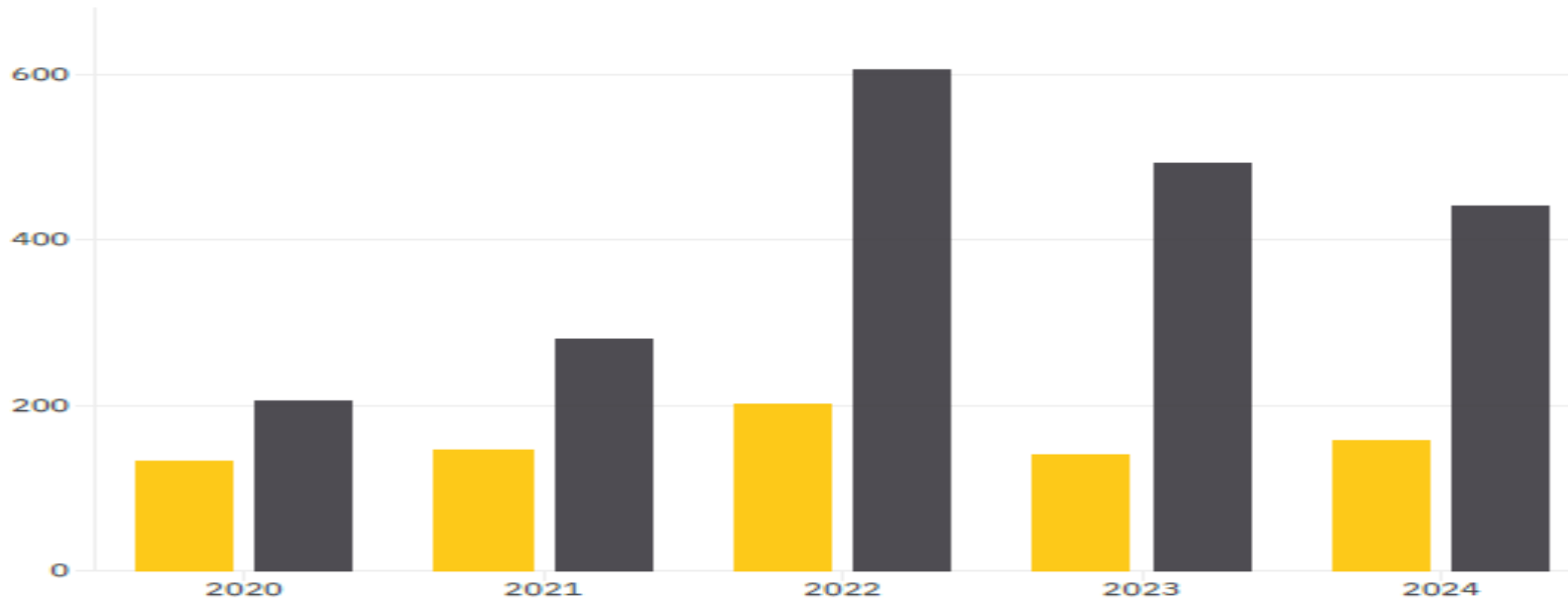
Fossil Fuels Subsidies vs Renewable Energy Subsidies – A trend to be reversed.....

Direct Fossil Fuel versus Renewable Energy Subsidies in Selected Countries, 2020-2024

Fossil fuel subsidies remain consistently higher than support for renewables, with a sharp increase in 2022 and continued gap across major economies

● Renewable Energy Subsidies ● Fossil Fuel Subsidies

USD billion



Source: IEA, 2026, IISD, 2026 (personal communication)⁷² -

Note: The figure includes estimated subsidies for fossil fuels that are consumed directly by end-users or consumed as inputs to electricity generation. It does not include indirect or implicit subsidies to fossil fuels.

REN21



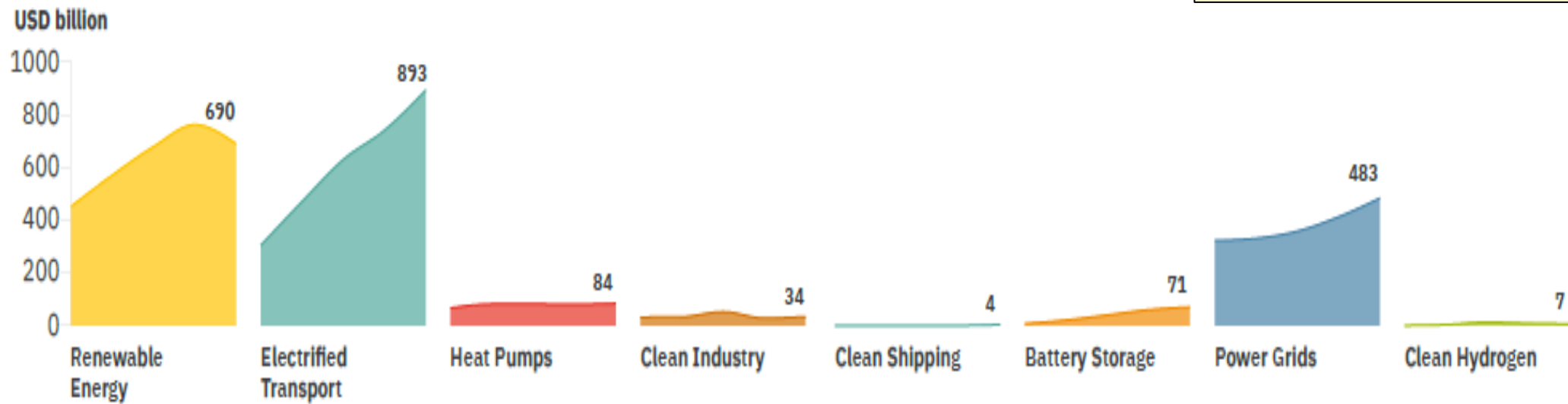
REN 21 Global Overview 2025

Global Investments in Renewables and Low-Emission Technologies

Global Investment in Renewables and Low-emission Technologies, 2021-2025

Investment is rising across most technologies, but renewable energy investment has declined in 2025

**Global Investment 2025:
2,3 G\$**

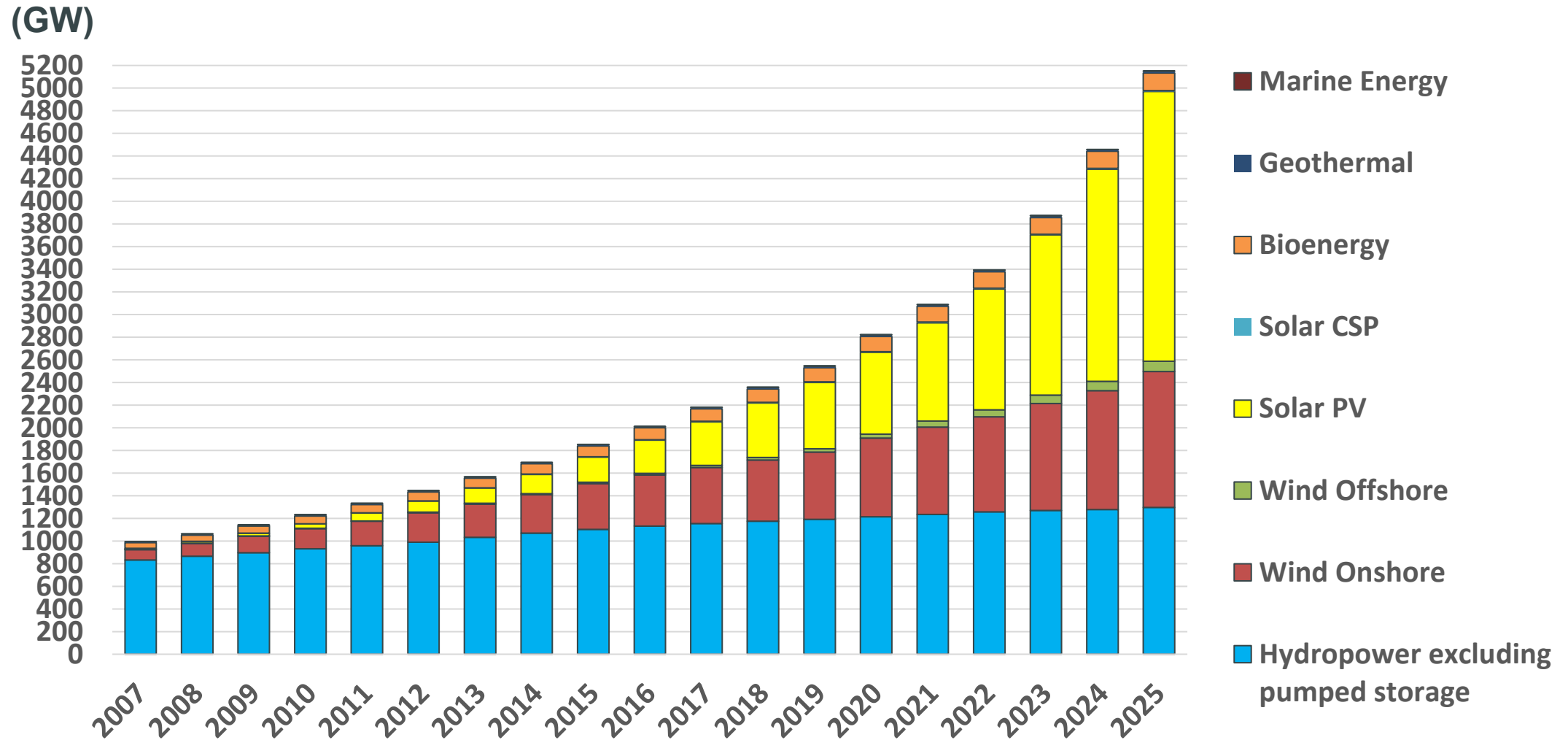


Source: BloombergNEF, 2026⁷⁸.

Note: Investment in electrified transport includes spending on all types of electric vehicles (electric cars, two- and three-wheelers, buses and trucks and fuel cell vehicles) and charging infrastructure (includes home and public charging but not private charging investment for commercial vehicles). Investment in clean industry includes bioplastics, circular economy, clean ammonia and clean steel. Clean shipping includes vessels with combustion engines that can use methanol, ammonia or hydrogen. Battery storage includes only utility-scale. Investment for "clean" hydrogen is captured here as defined by BNEF.



Evolution of Renewable Power Capacity, including Hydropower: 1000 GW in 2007, # 5200 GW in 2025

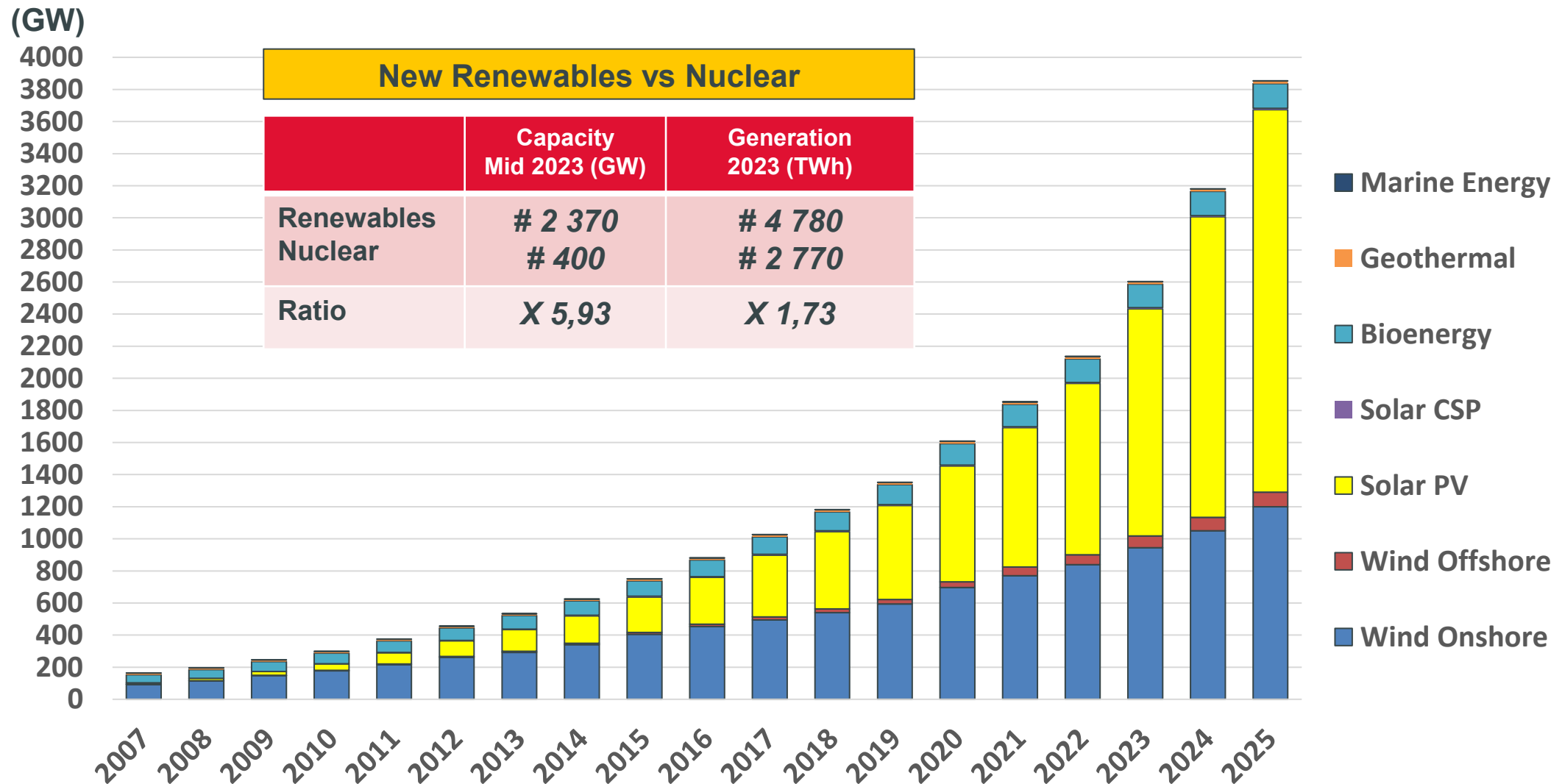


Source: ChG/Data from IRENA Renewable Capacity Statistics April 2026
Bioenergy includes solid & liquid biofuels, bagasse, renewable waste

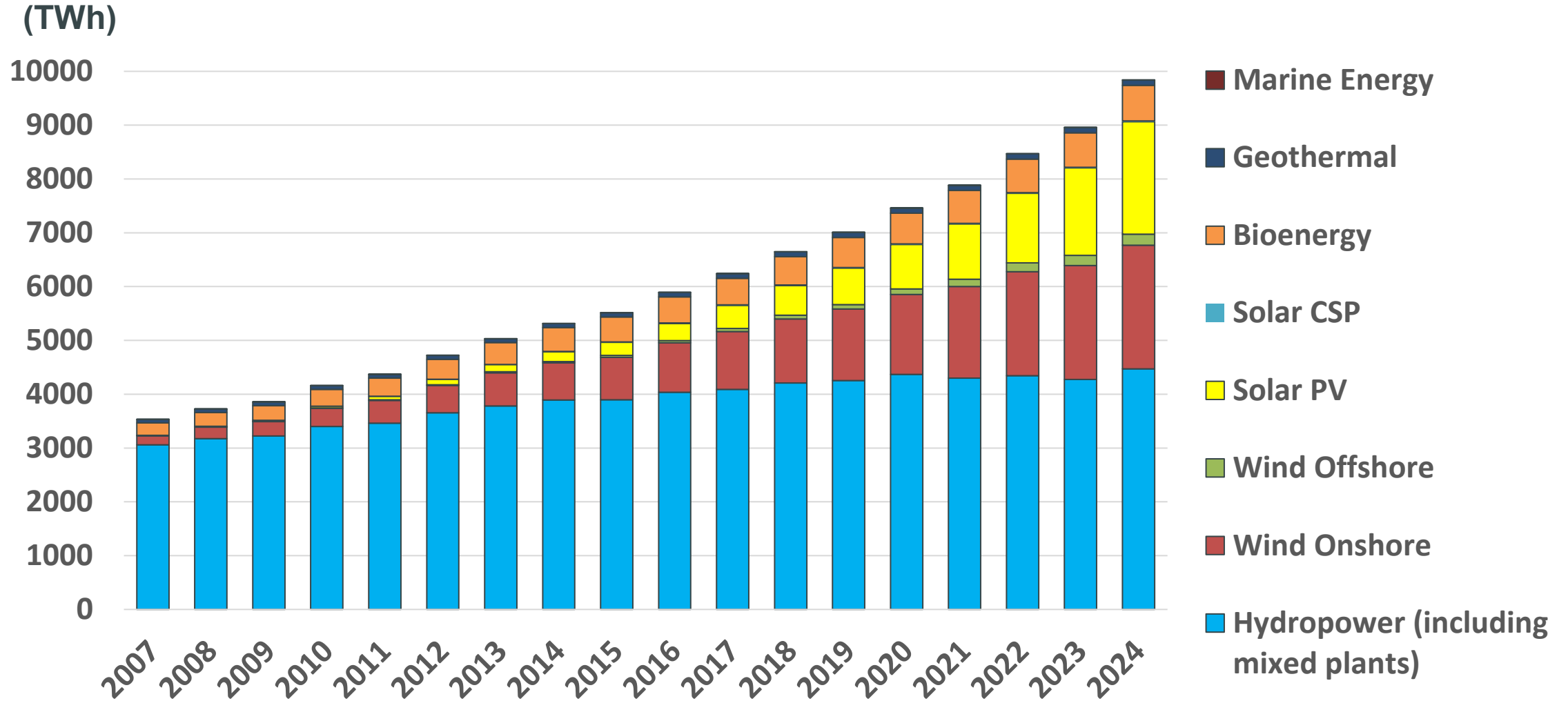


Evolution of Renewable Power Capacity, excluding Hydropower

160 GW in 2007, # 3 900 GW in 2025



Key position of Hydropower in the Renewable Electricity Generation worldwide



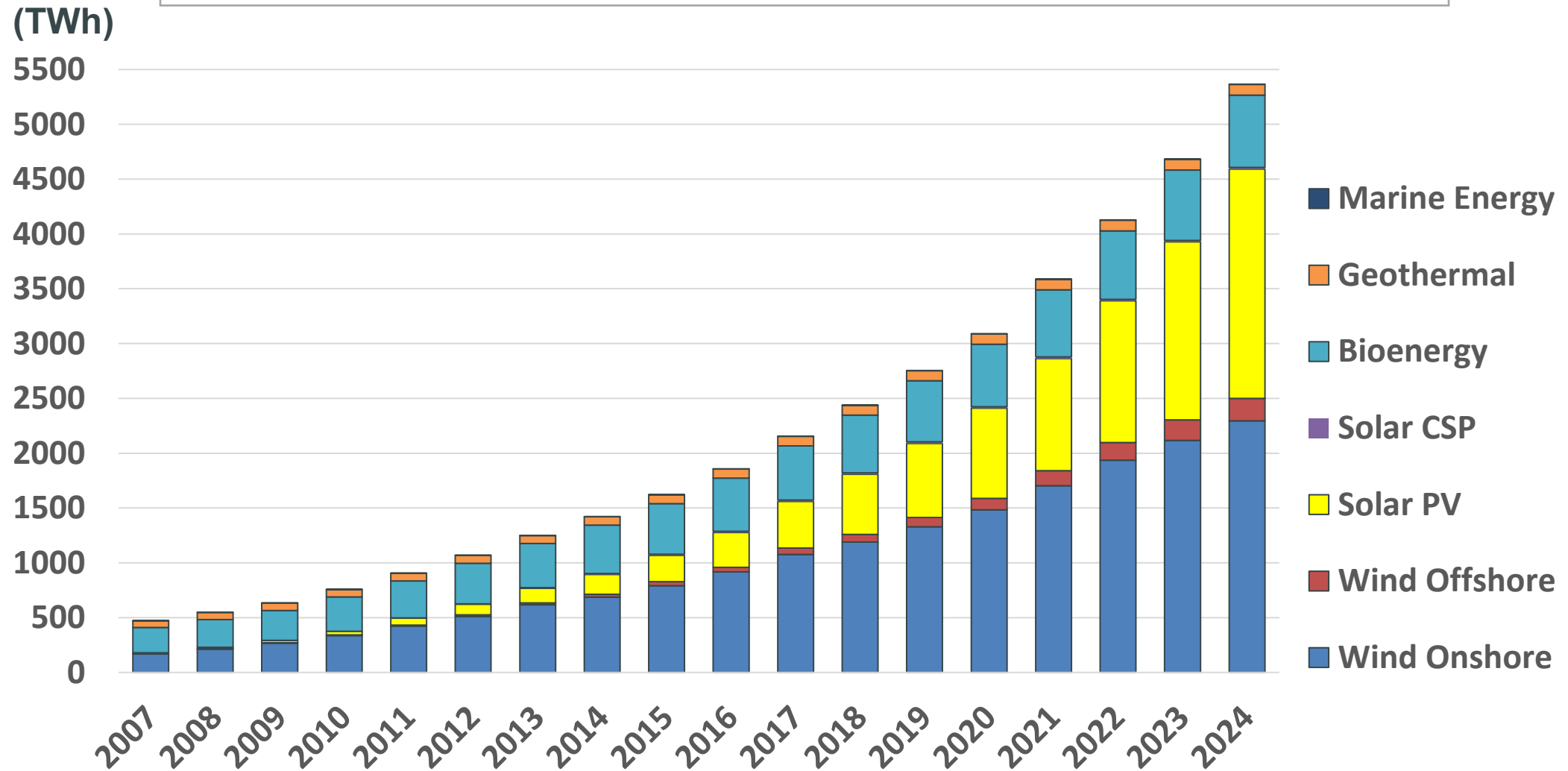
Source: Data from IRENA Renewable Energy Statistics 2026

Nota: Hydro excludes pump storage & includes mixed plants

Bioenergy includes solid & liquid biofuels, bagasse, renewable waste³⁰



Top 3 in the Renewable Electricity Generation worldwide excluding hydropower: Wind Onshore, Solar PV, Bioenergy



Source: Data from IRENA Renewable Energy Statistics 2026

Nota: Hydro excludes pump storage & includes mixed plants

Bioenergy includes solid & liquid biofuels, bagasse, renewable waste³¹

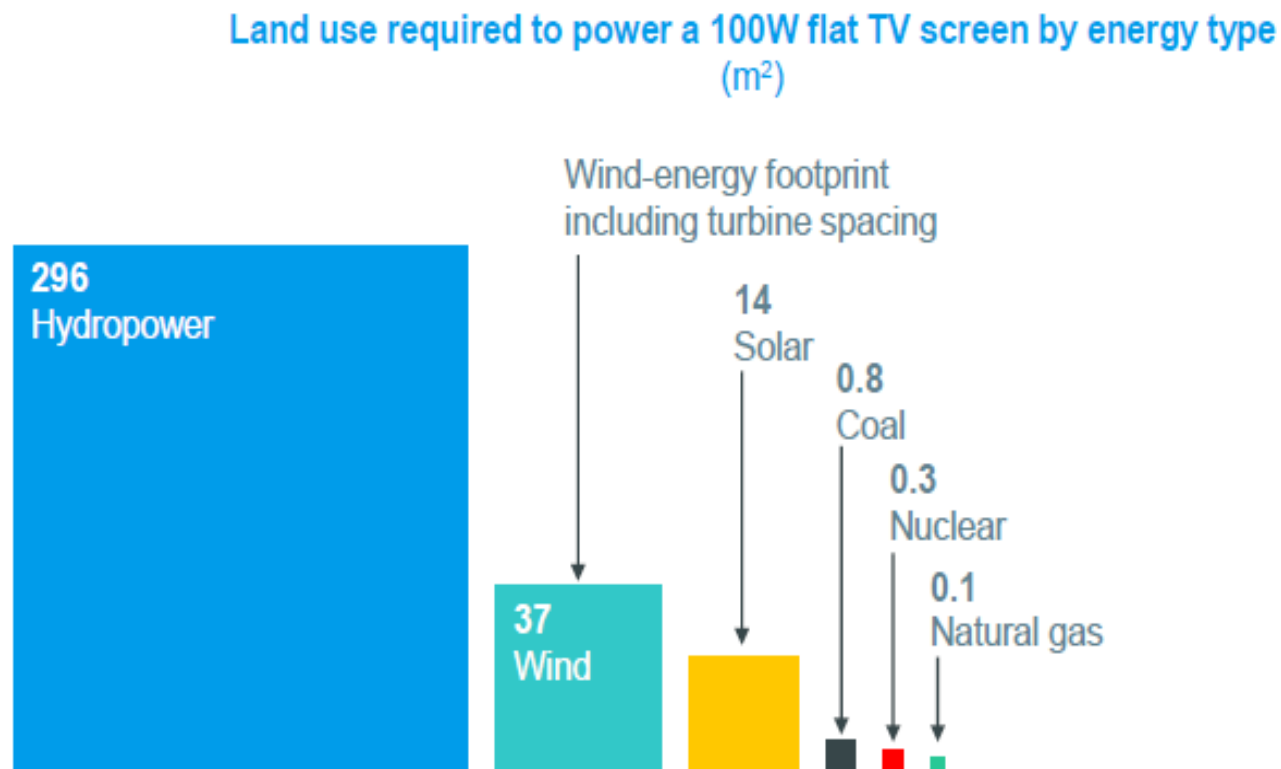




Hydroelectric Power and **Biomass** are today the most important contributors to renewable energy in the primary energy mix (12%)



Also, some constraints to be accounted for



Acceptability issues of solar & wind due to their impact on territories and landscape must be overcome

Source: TotalEnergies-Cap Gemini/Energy Landscape September 2021



What Dam is it?



Pb of Acceptability of Land Usage, Solar plants, Wind farms,....



Some examples – Historical evolution



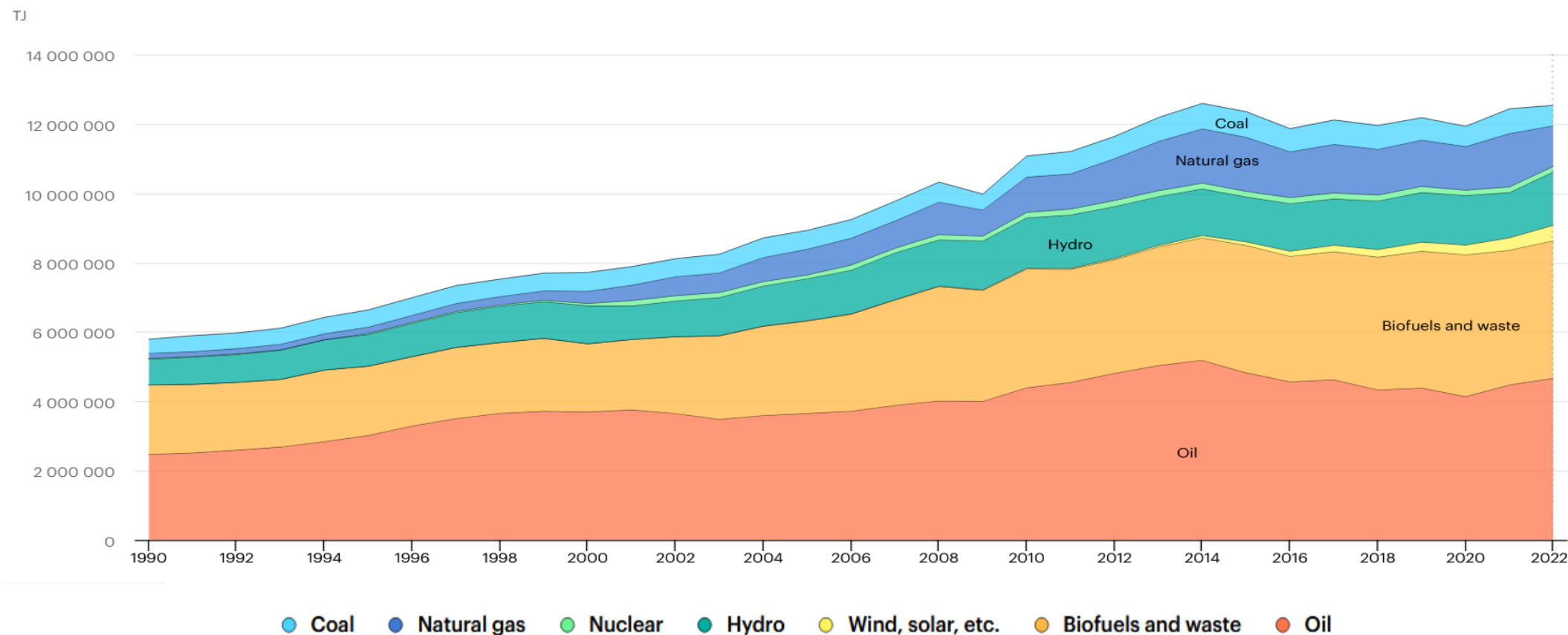
Example 1: Brazil



The Case of BRAZIL

Brazil energy mix evolution 1990 – 2022

Important Growth of Bioenergy



Source; IEA Key Energy Statistics 2021

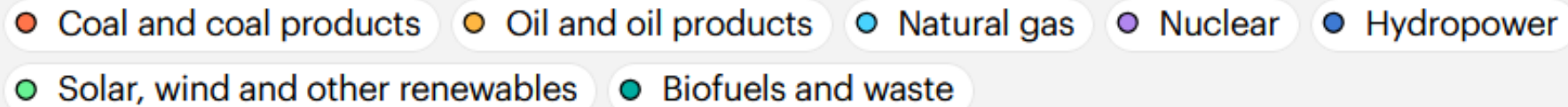
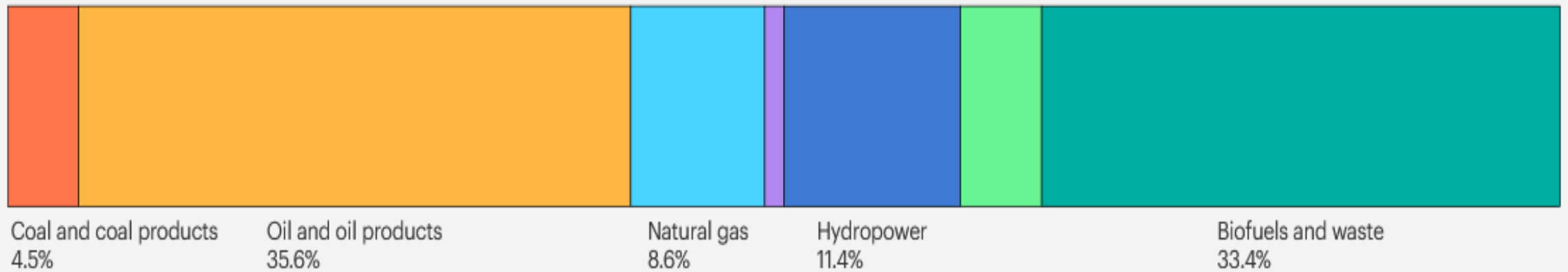


The Case of BRAZIL

Brazil energy mix 2023

Oil, Biofuels & Hydroelectricity

Total energy supply, Brazil, 2024



The Case of BRAZIL

44% of Renewables in the Energy Mix

In Brazil, Renewables represent around # 50 % of primary energy supply in 2024, as follows:

Bioenergy and other Renewables: 39%*
Hydroelectricity : 11%

***Includes Waste; Sugar cane, Wood, Charcoal, Solar, Wind.**

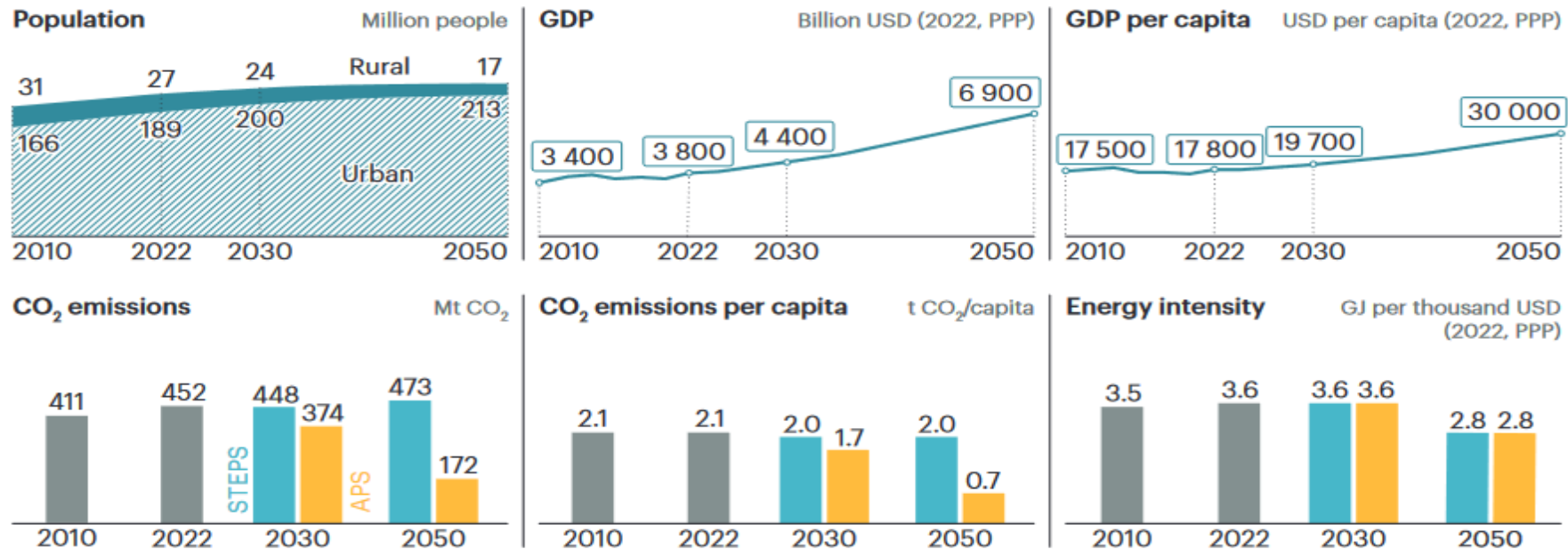
Oil represents 36% of Primary Energy Supply and Brazil will become soon an oil exporters thanks to deep water production developments.

Negative aspect: Deforestation



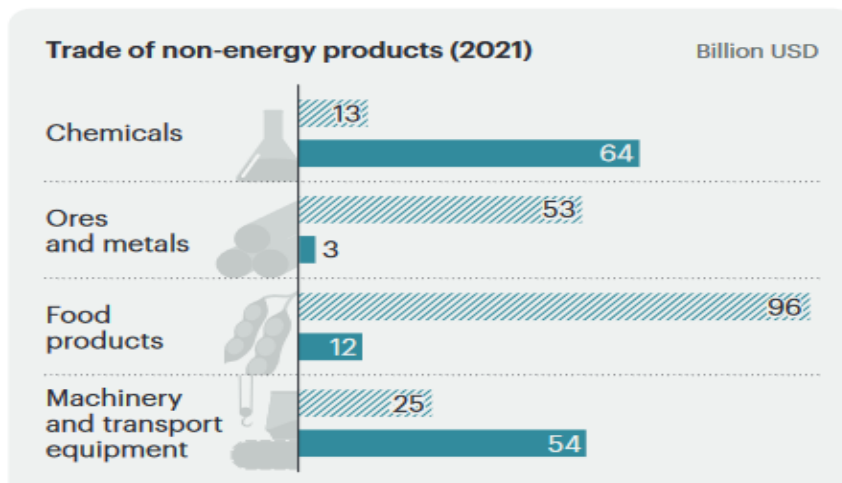
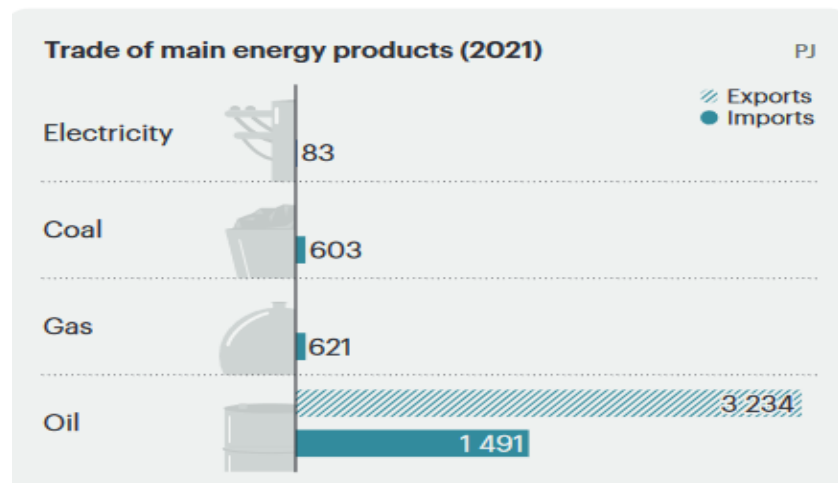
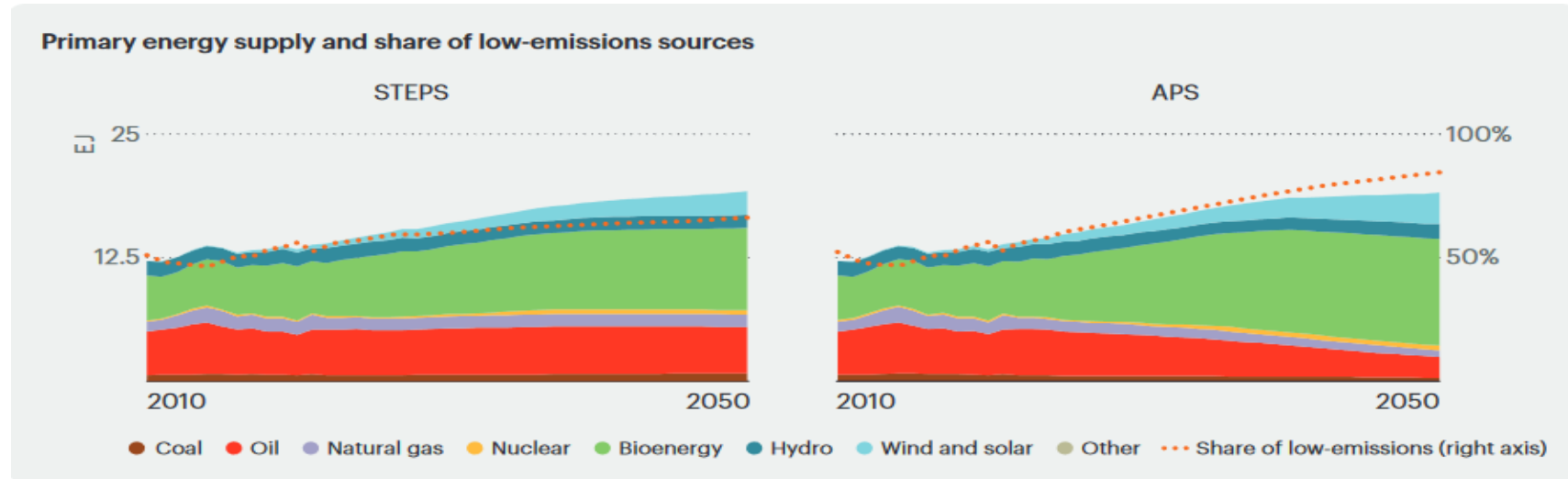
The Case of BRAZIL

General Features



The Case of BRAZIL

General Features



The Case of BRAZIL

Energy Policy

	Policy	Publication year
Economy-wide measures	• NDC: 50% reduction of GHG emissions by 2030 from 2005 levels.	2022
	• Net zero emissions by 2050 target.	2022
	• Guidelines for a National Strategy for Climate Neutrality: between 45% and 50% of renewable energy in the national energy mix by 2030.	2022
	• Decennial Energy Expansion Plan 2032 (PDEE 2032) (indicative).	2023
Just transition policies	• Amazon Decarbonisation Programme: Reduce diesel power plant generation in the Amazon region by 40% by 2026, USD 1 billion.	2023
	• <i>Luz para todos</i> programme (initially launched in 2003): To bring electricity to 500 000 families that lack access by 2026.	2023
	• <i>Novo PAC</i> : USD 105 billion for the energy transition and energy security.	2023
AFOLU	• Action Plan: Zero deforestation by 2030 (5th phase).	2023
Environment and water resources	• <i>Metano Zero</i> programme: 25 new biomethane plants (2.3 mcm/d in 2027).	2022
	• Hydropower Reservoir Recovery Plan: Improve water management.	2022
Hydrogen	• 2023-2025 Working Plan of the National Hydrogen Programme.	2023
Power	• Revised subsidies for distributed generation (net billing scheme).	2022
Industry	• Energy Efficiency Programme: Public funds (about USD 117 million in 2020).	2020
Transport	• RenovaBio Programme - National Biofuel Policy.	2017
	• National Bio Kerosene Programme: Promotes R&D for biofuel for aviation.	2021
	• <i>Combustível do Futuro</i> programme: Targets 30% bioethanol and 15% biodiesel blending rate.	2021



The Case of BRAZIL

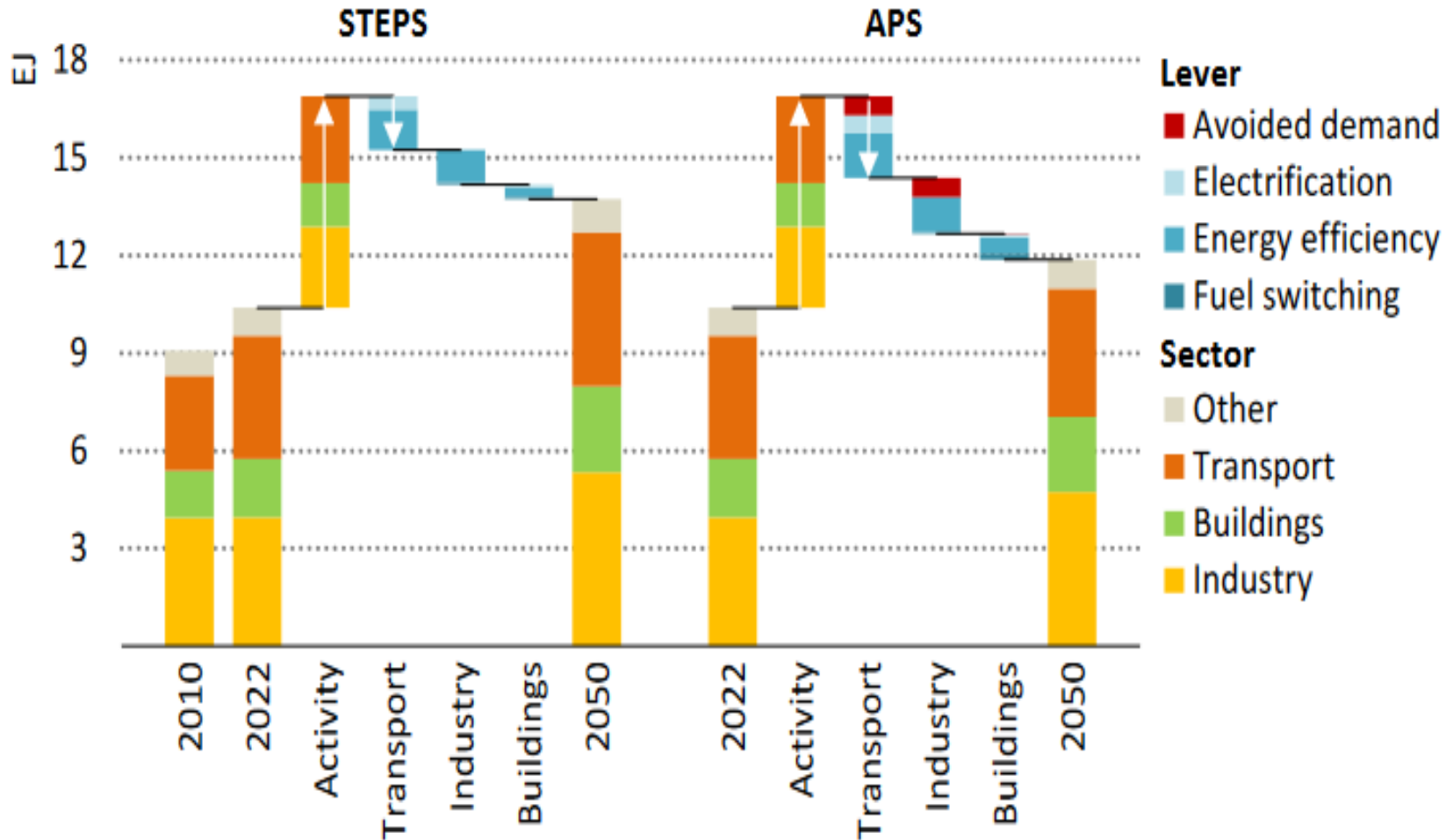
Major infrastructures in Brazil

	Project	Size	Date online	Status	Description
Oil and gas	Pre-salt (Etapa 3 & 4)	+0.5 mb/d (target 2.2 mb/d)	2027	●	Oil and gas
Hydrogen/ ammonia	Port of Pecem - Base One	600 kt H ₂ /year (production)	2025	●	Dedicated hydro
	Unigel, phase I	10 kt H ₂ /year (capacity)	2023	●	Dedicated wind
Nuclear	Angra 3	1 405 MWe	2028	●	Nuclear reactor
CCUS	Lucas do Rio Verde, FS Bioenergia	0.4 Mt CO ₂ /year	2030	●	BECCS
Transmission, interconnections	Graça Aranha– Silvânia (HVDC)	800 kV	2028	●	1 440 km
Status ● Feasibility study ● Under construction					



The Case of BRAZIL

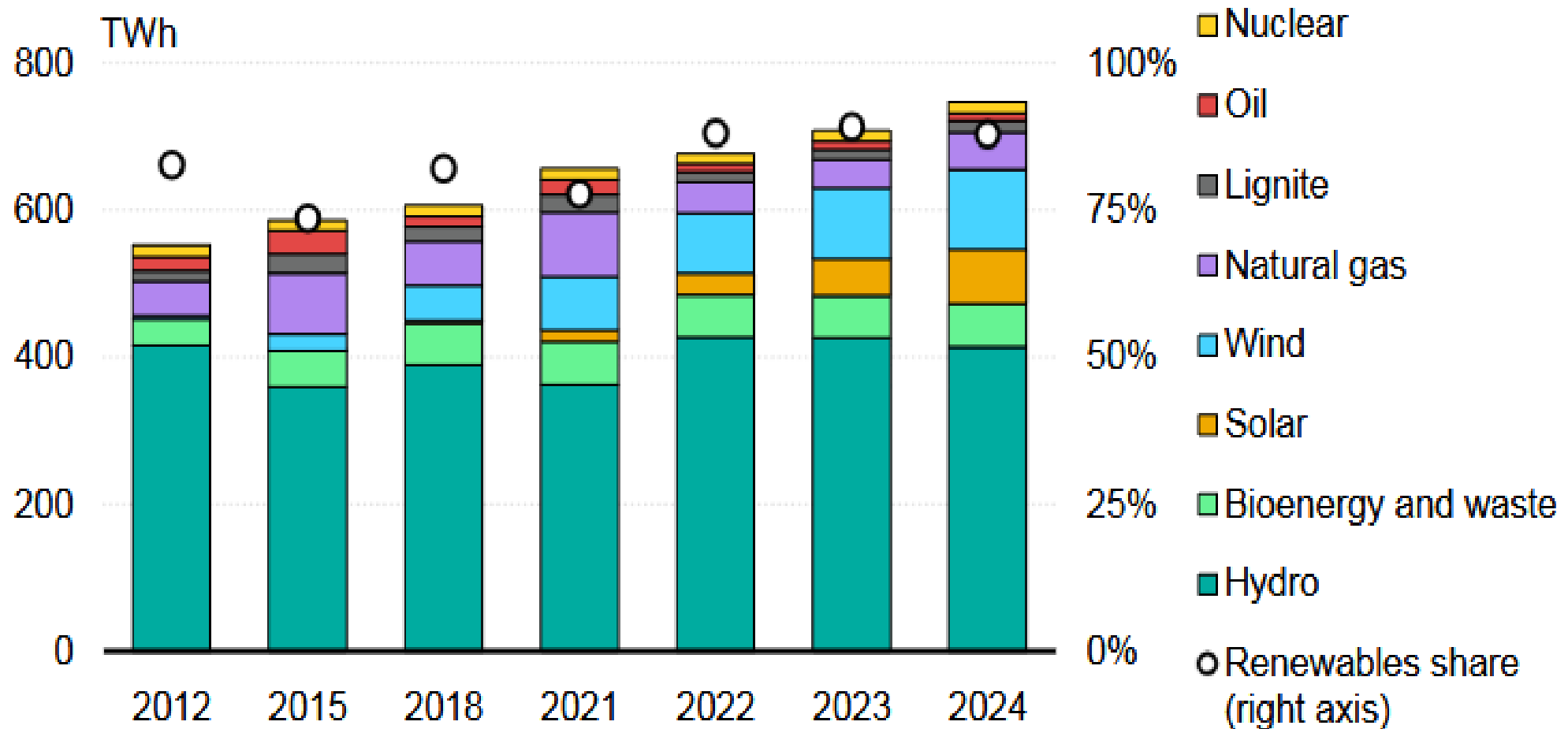
Final Energy Consumption



The Case of BRAZIL - Electricity Generation 2000-2018

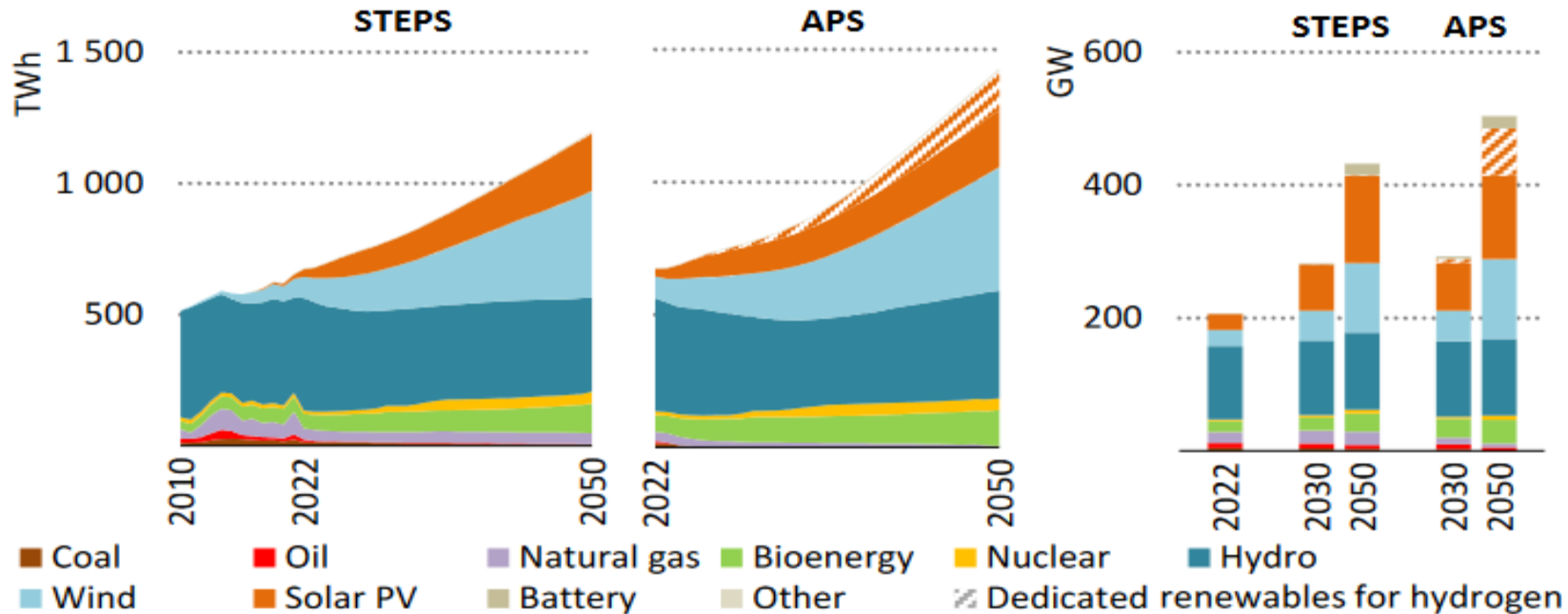
Hydroelectricity N°1

Electricity generation by source in Brazil, 2012-2024



The Case of BRAZIL

Electricity Generation by Fuels & Scenarios



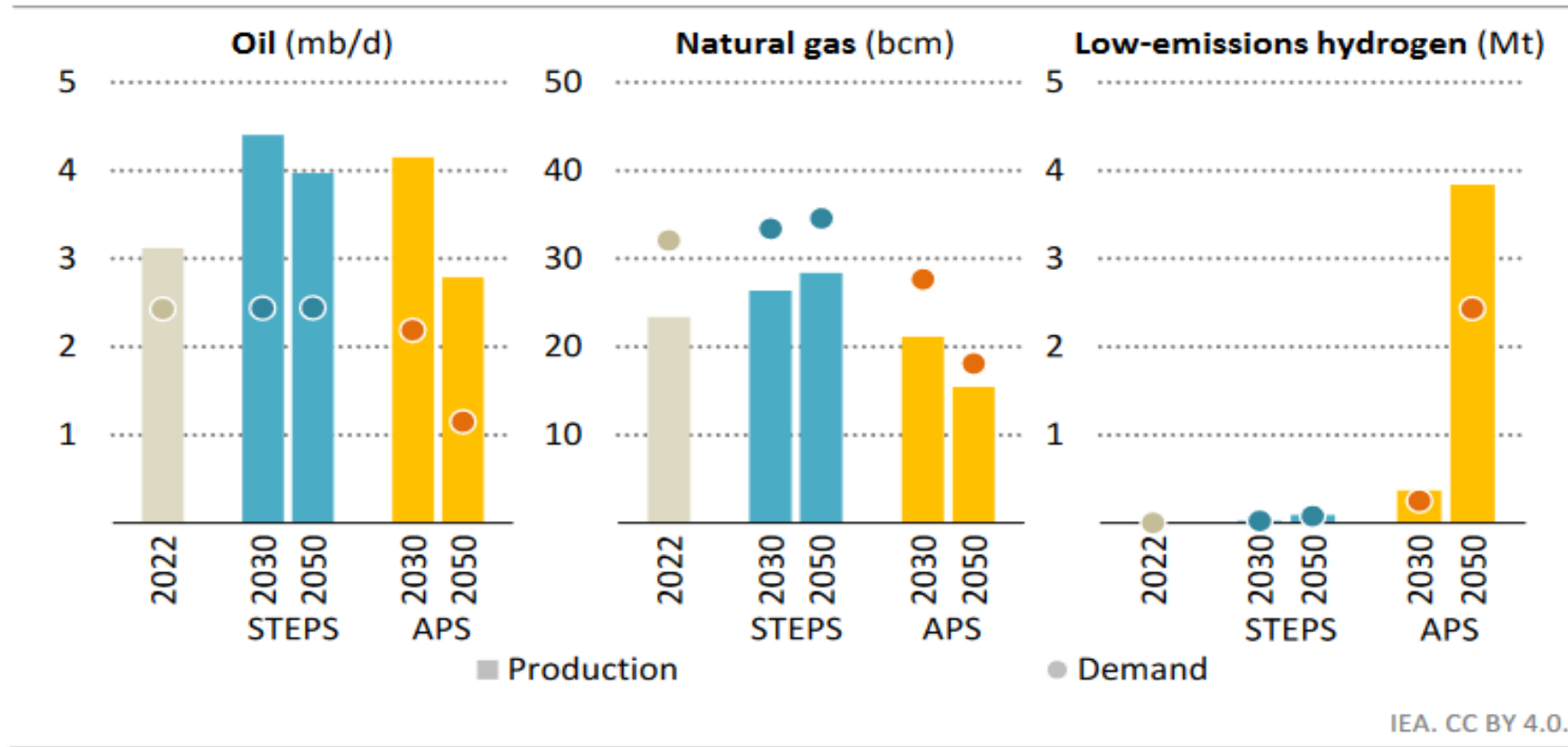
IEA. CC BY 4.0.

- Hydropower dominates the current power mix, but its expansion in both scenarios is constrained by inherent resource limits and social acceptance concerns.
- Wind and solar PV meet nearly all electricity demand growth. In the APS, they account for nearly 60% of electricity generation in 2050 compared with 17% today.



The Case of BRAZIL

Fuels Demand & Production vs Scenarios



- Oil production in the STEPS increases from 3 mb/d to just over 4 mb/d by 2030; natural gas production grows in response to rising demand in the STEPS but declines in the APS.
- In the APS, hydrogen production reaches 4 Mt in 2050 boosted by the national strategy.



Itaipu Dam



Example 2: European Union



EU: The Key Drivers - 3x20% by 2020

European Council March 2007, integrated in the law in 2009

+ 20% by 2020
EFFICIENCY

By 2020 - 20% GHG vs 1990

By 2020 20% RENEWABLES
(France: 23%)

BIO-FUELS

10 % 2020
binding

E-ELECTRICITY

HEATING & COOLING

NATIONAL TARGETS and ACTION PLANS



EU: The Key Drivers - 32%x40%x32% by 2030

New objectives of European Council 2018, for the period 2021-2030

+ 32,5% by 2030
EFFICIENCY

By 2030 - 40% GHG vs 1990

By 2030 32% RENEWABLES

BIO-FUELS

- 1st Generation Biofuels frozen at their 2020 level and < 7%
- Palm Oil: 0 as from 2030
- Other modern Biofuels and Biogas > 3,5%

E-ELECTRICITY

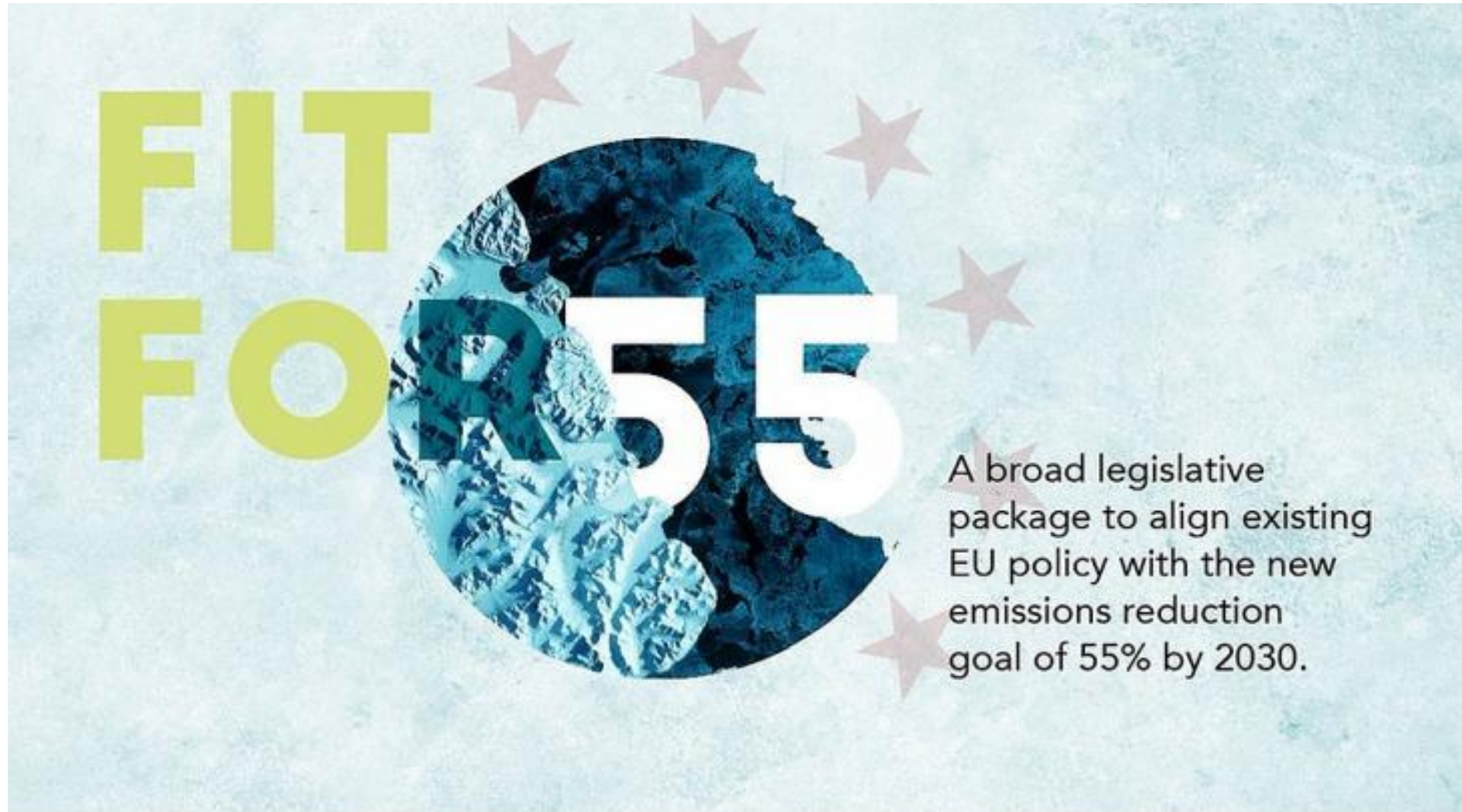
HEATING & COOLING

NATIONAL TARGETS and ACTION PLANS

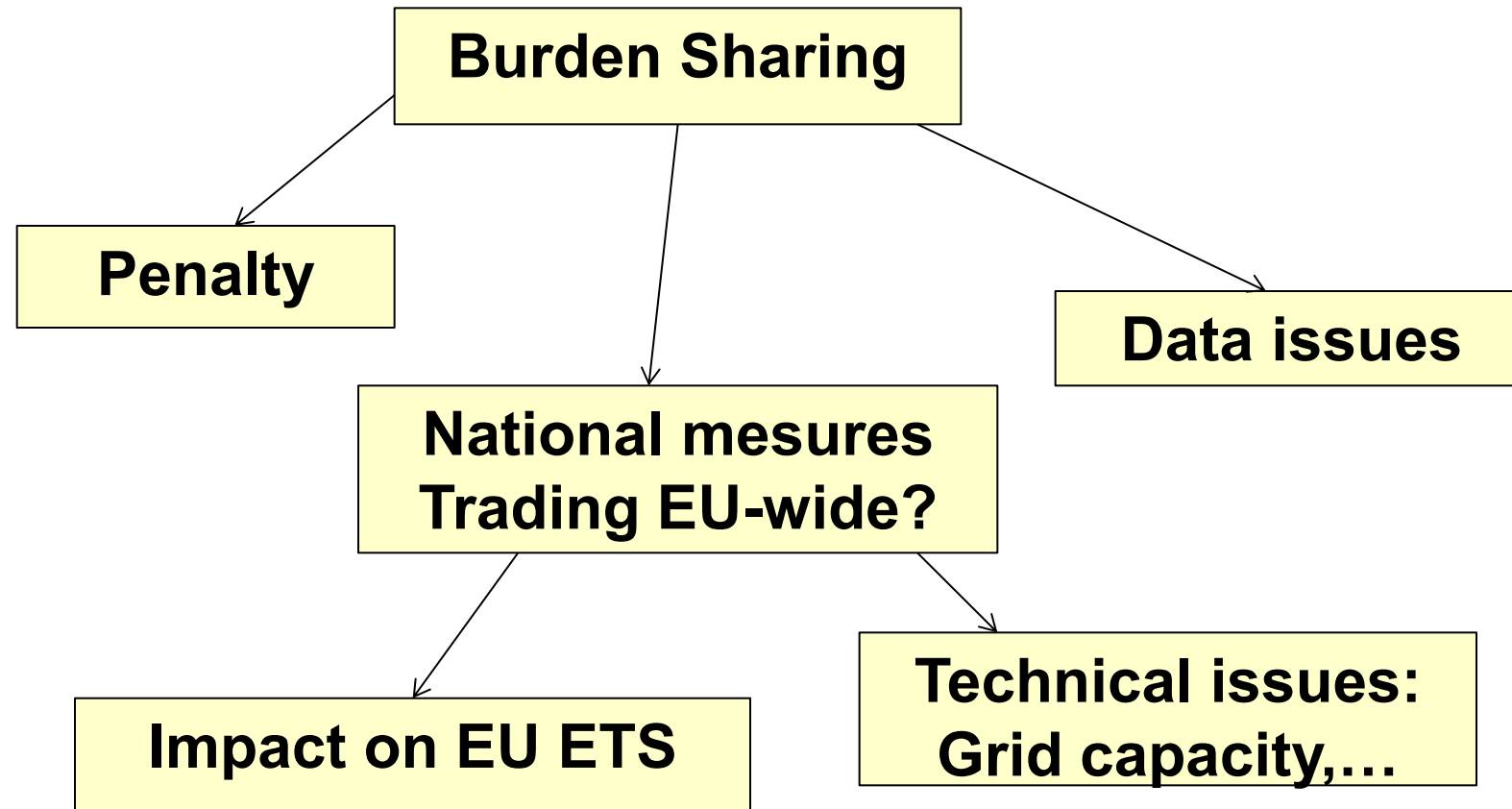


New objectives of European Council 2021

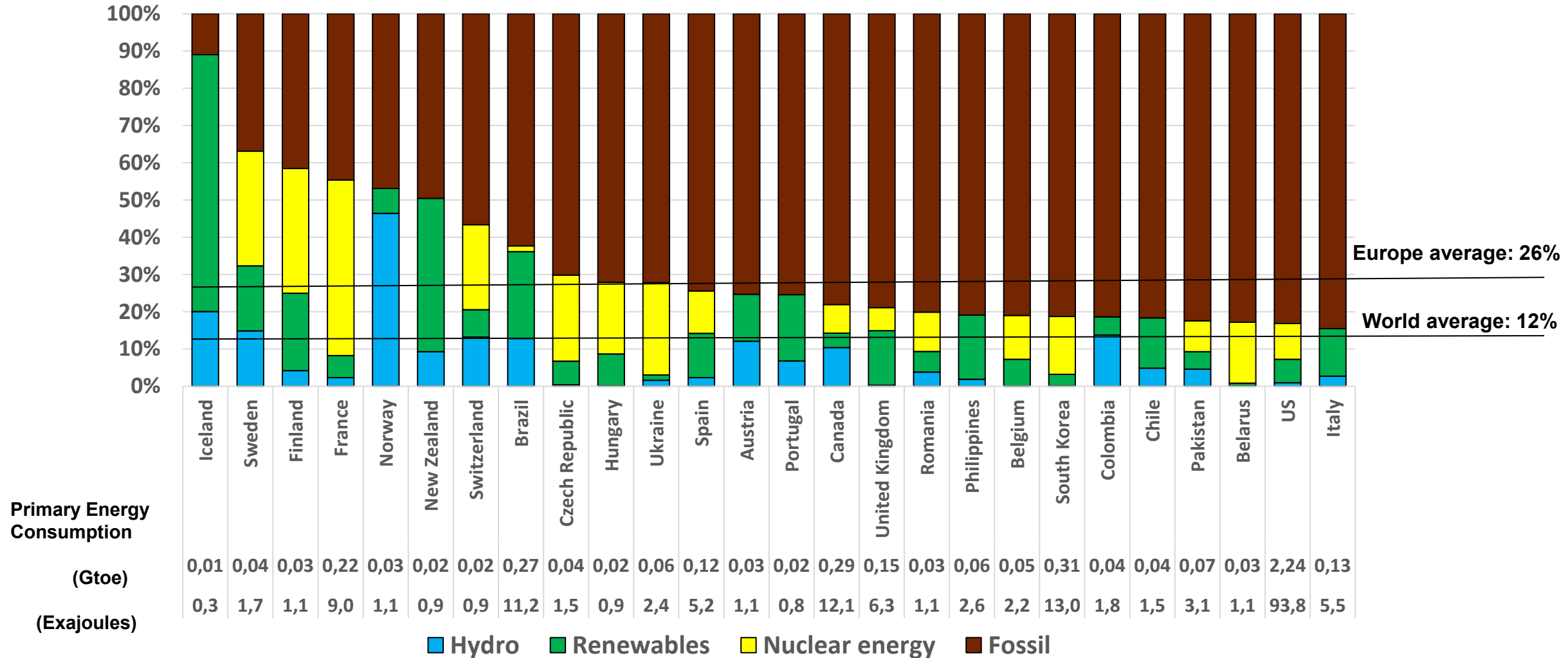
-55% GHG Emissions by 2030 vs 1990



The EU Policy = A 32% Renewables share by 2030: Policy issues to resolve for achieving the objective



Share of decarbonated Primary Energy in the Energy mix by countries – 2025, ranked by decarbonated Energy Consumption



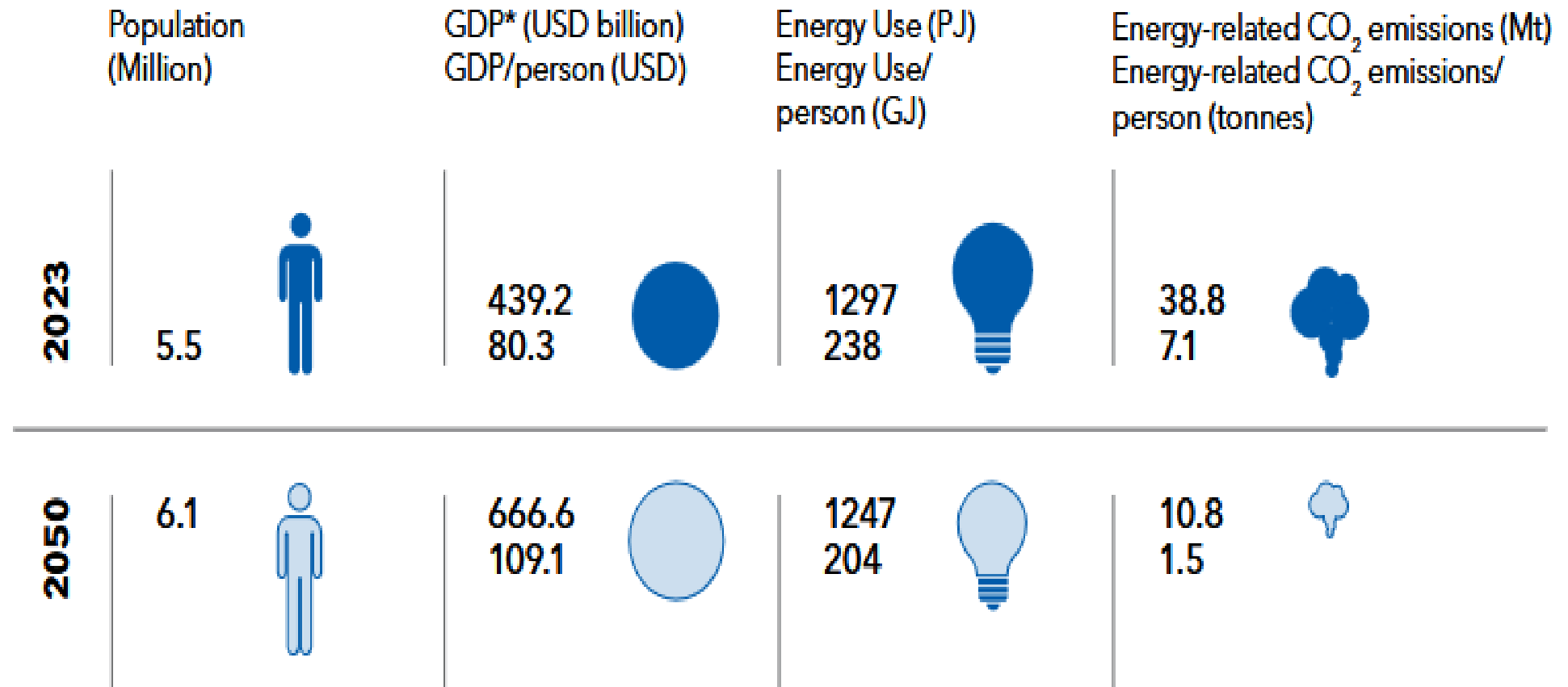
Example 3: Norway



Hydroelectricity in Norway



Norway - Main figures 2023 & 2050



*All GDP figures in the report are based on 2017 purchasing power parity and in 2023 international USD



Norway - Main policy factors

Policy factors included in our Outlook



1. Renewable power support



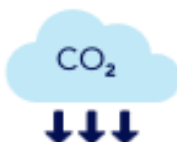
2. Energy storage support



3. Zero-emission vehicle support



4. Hydrogen support



5. CCS, DAC support



6. Energy-efficiency standards



7. Bans, phase-out plans, mandates



8. Carbon pricing schemes



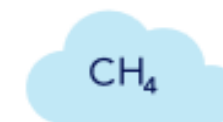
9. Fuel, energy, and carbon taxation



10. Air pollution intervention



11. Plastic pollution intervention

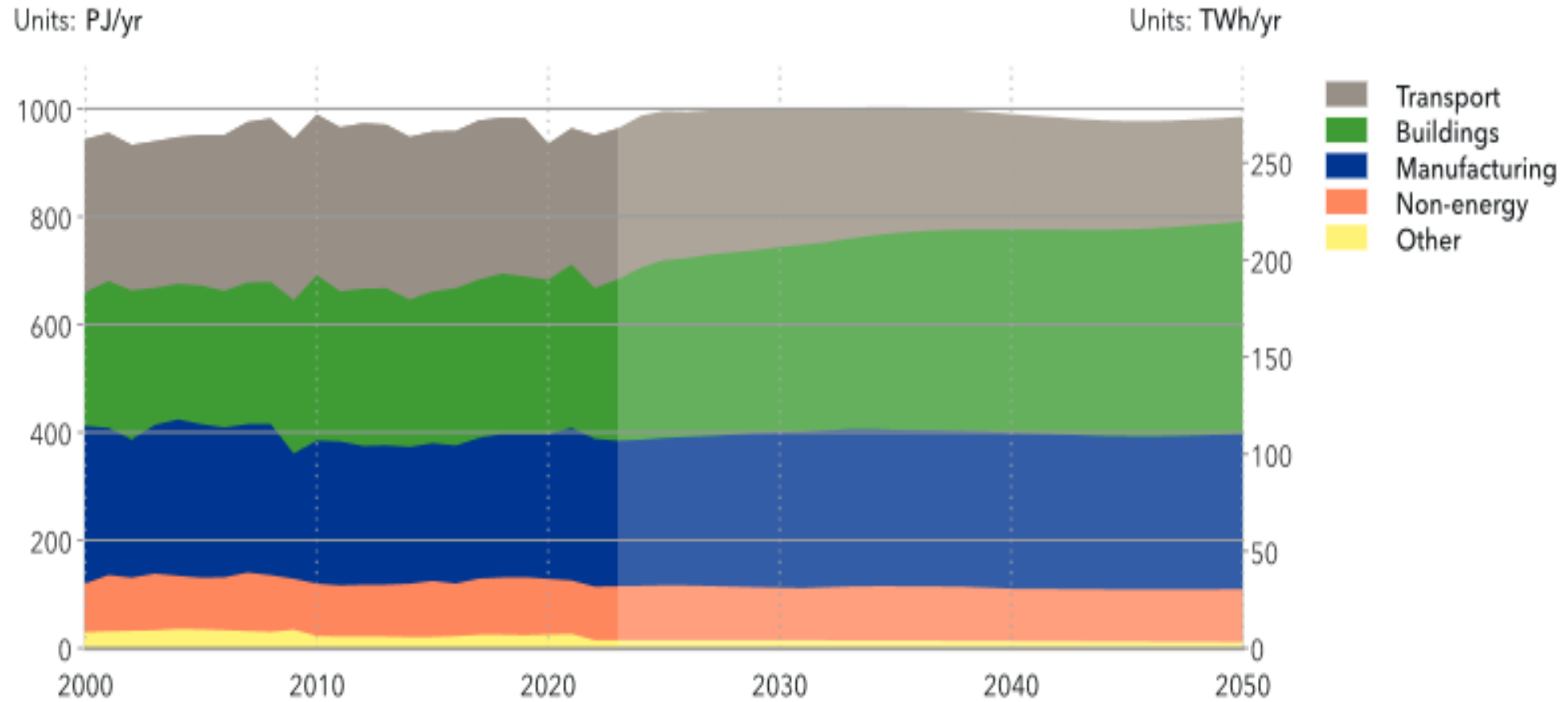


12. Methane intervention



Norway - Energy Demand

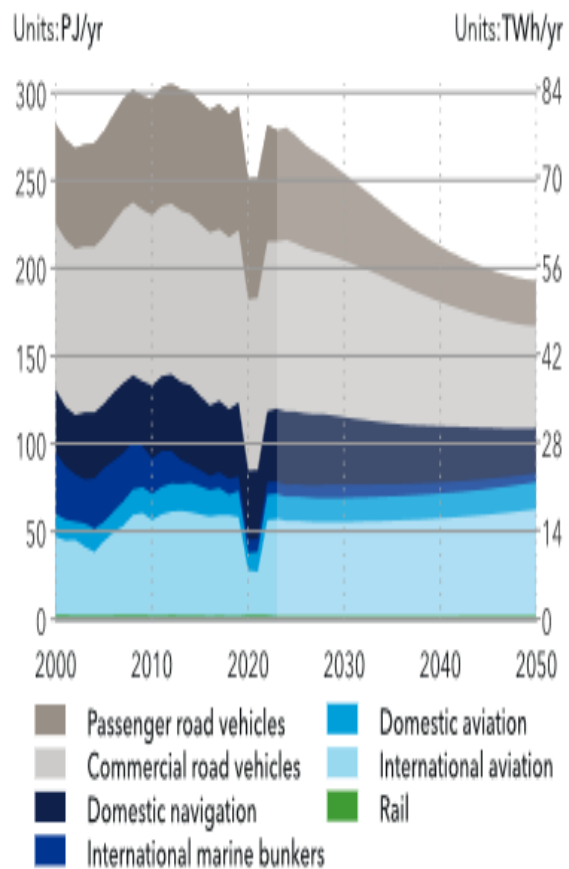
Norway final energy demand by sector



Historical data source: IEA WEB (2024), SSB (2024)

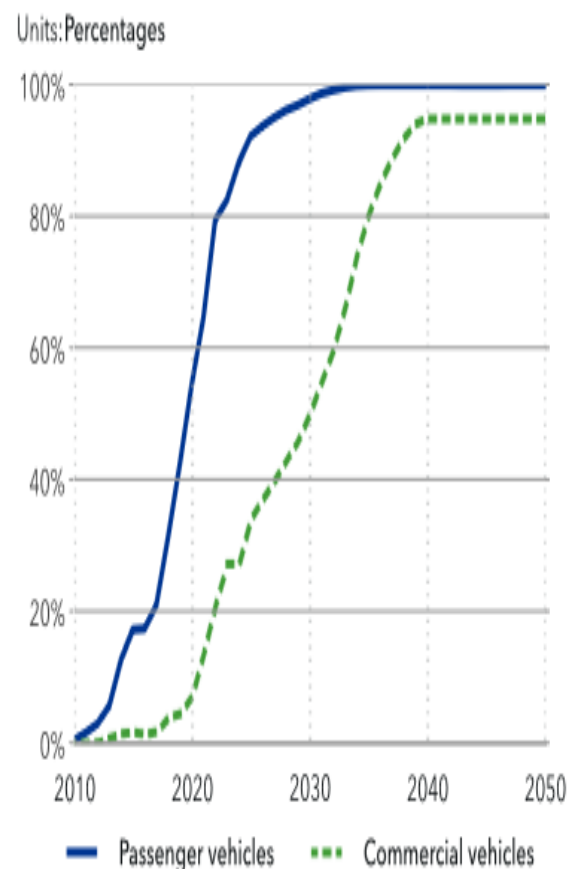
Norway - Priority to Electric Vehicles

Norway transport sector energy demand by subsector



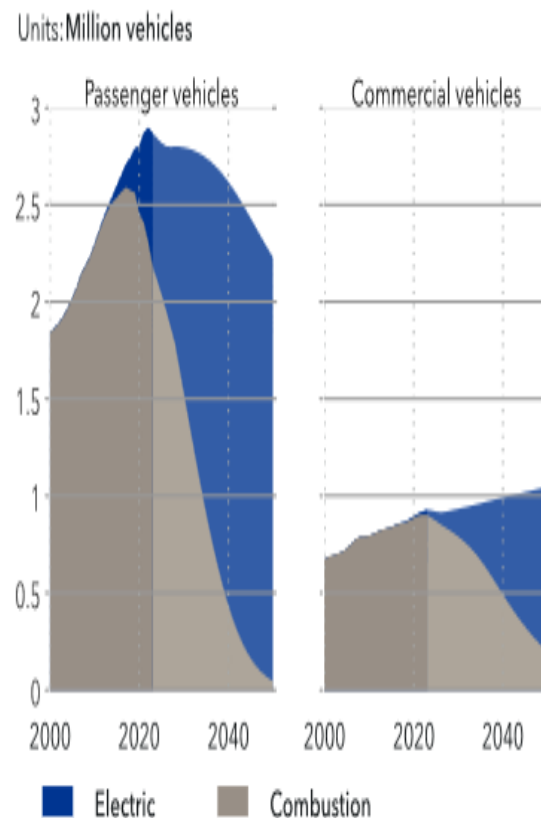
Historical data source: IEA WEB (2024), SSB (2024)

Norway market share of electric vehicles



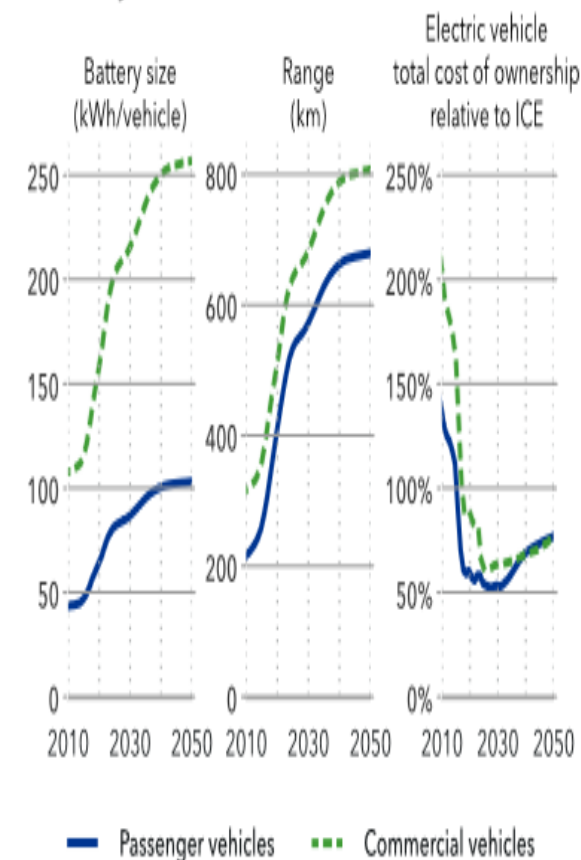
Historical data source: IEA WEB (2024), SSB (2024)

Norway number of road vehicles by type and drivetrain



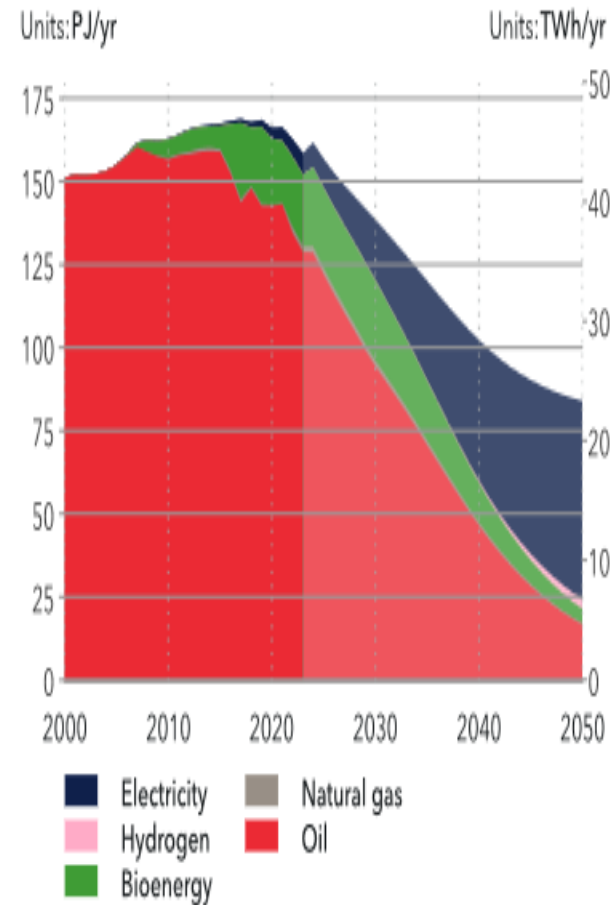
Combustion vehicles include ICEs and PHEVs. Electric vehicles include BEVs and FCEVs. Historical data source: SSB (2024)

Development of key parameters of electric vehicles in Norway



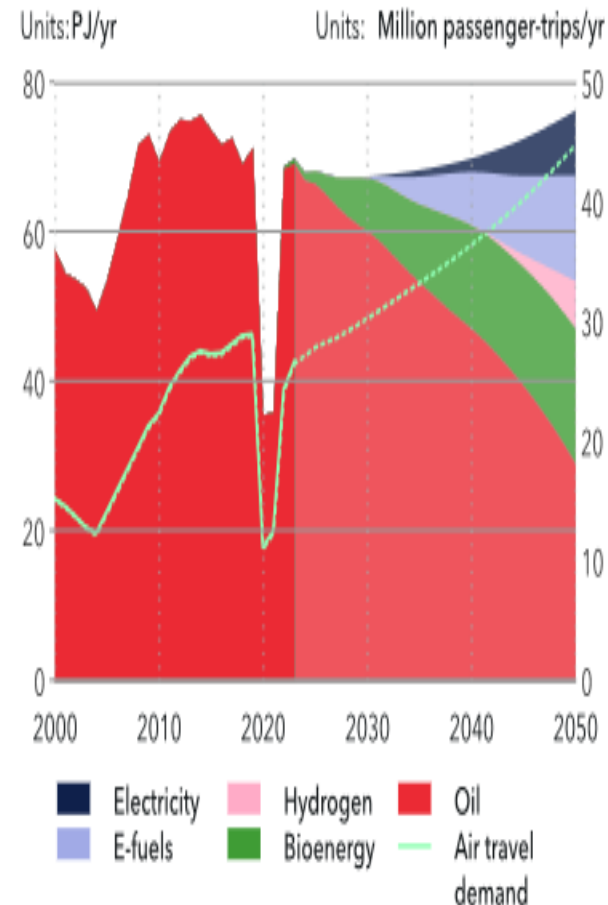
Norway - Transport Sector

Norway road subsector energy demand by carrier



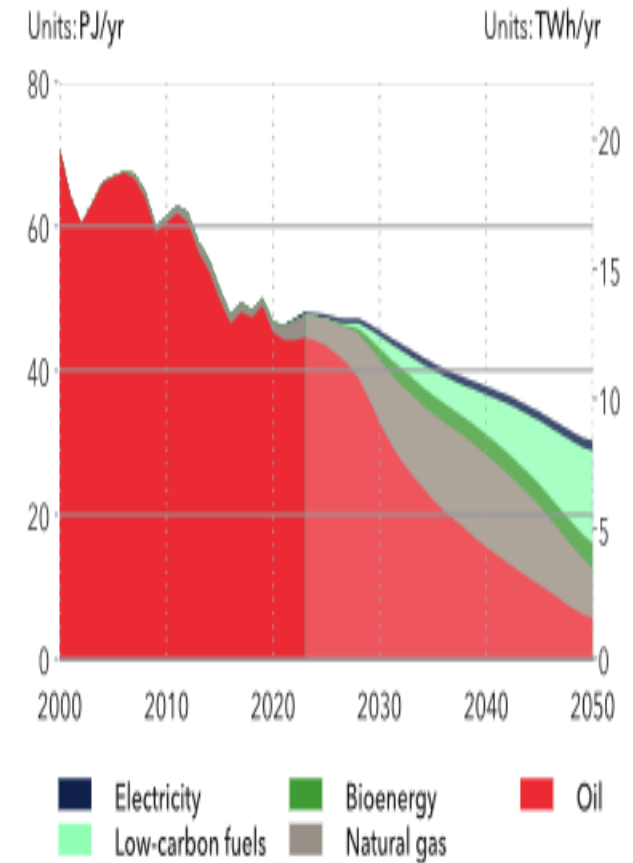
Natural gas includes LPG. Historical data source: IEA WEB (2024), SSB (2024)

Norway aviation subsector energy demand by carrier



Historical data source: IEA WEB (2024), SSB (2024)

Norway maritime subsector energy demand by carrier



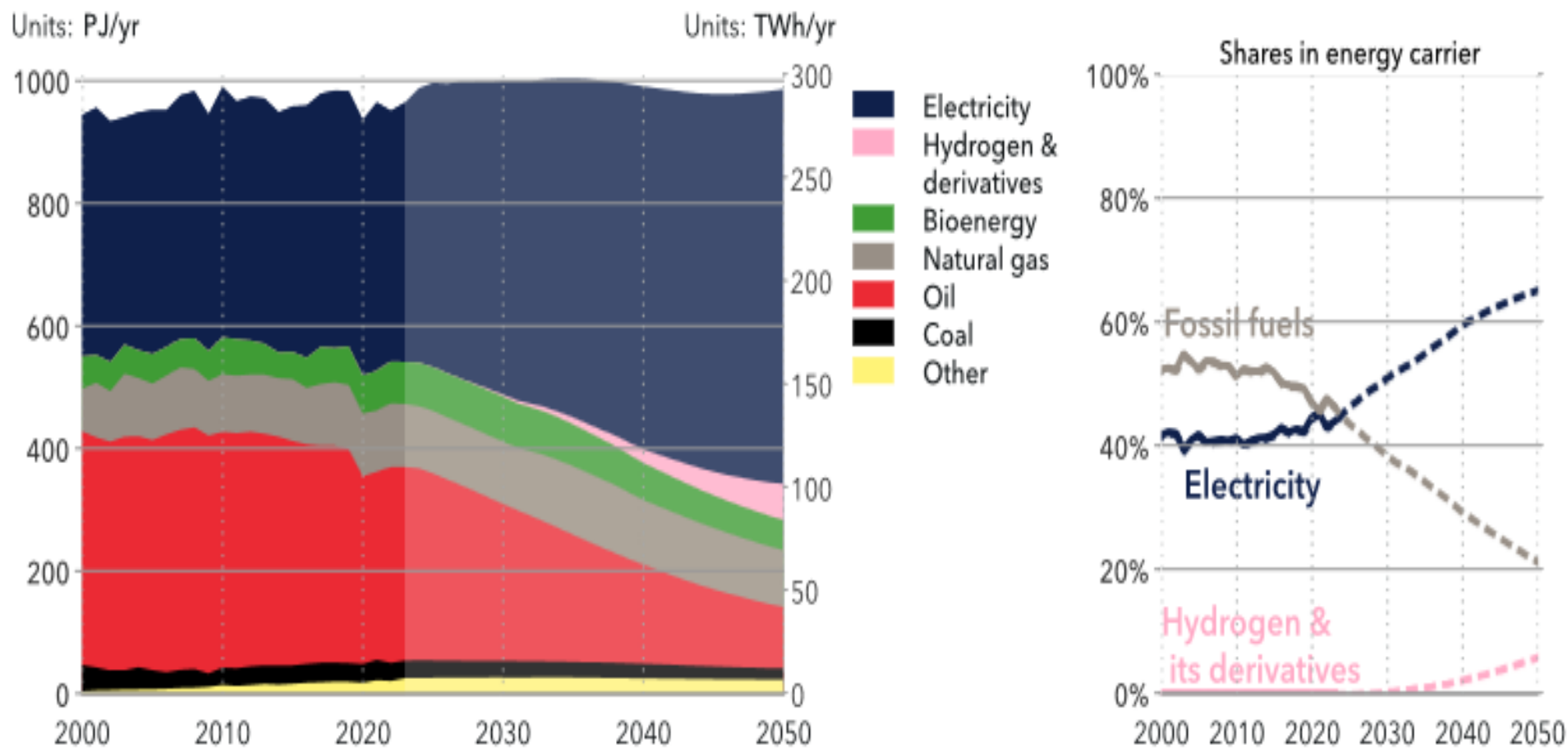
Natural gas includes LNG and LPG. Fuel mix given by best-estimate assessment, not model output. Historical data source: IEA WEB (2024), SSB (2024)

Source: Norway DNV 2024



Norway - Final Energy Demand

Norway final energy demand by carrier

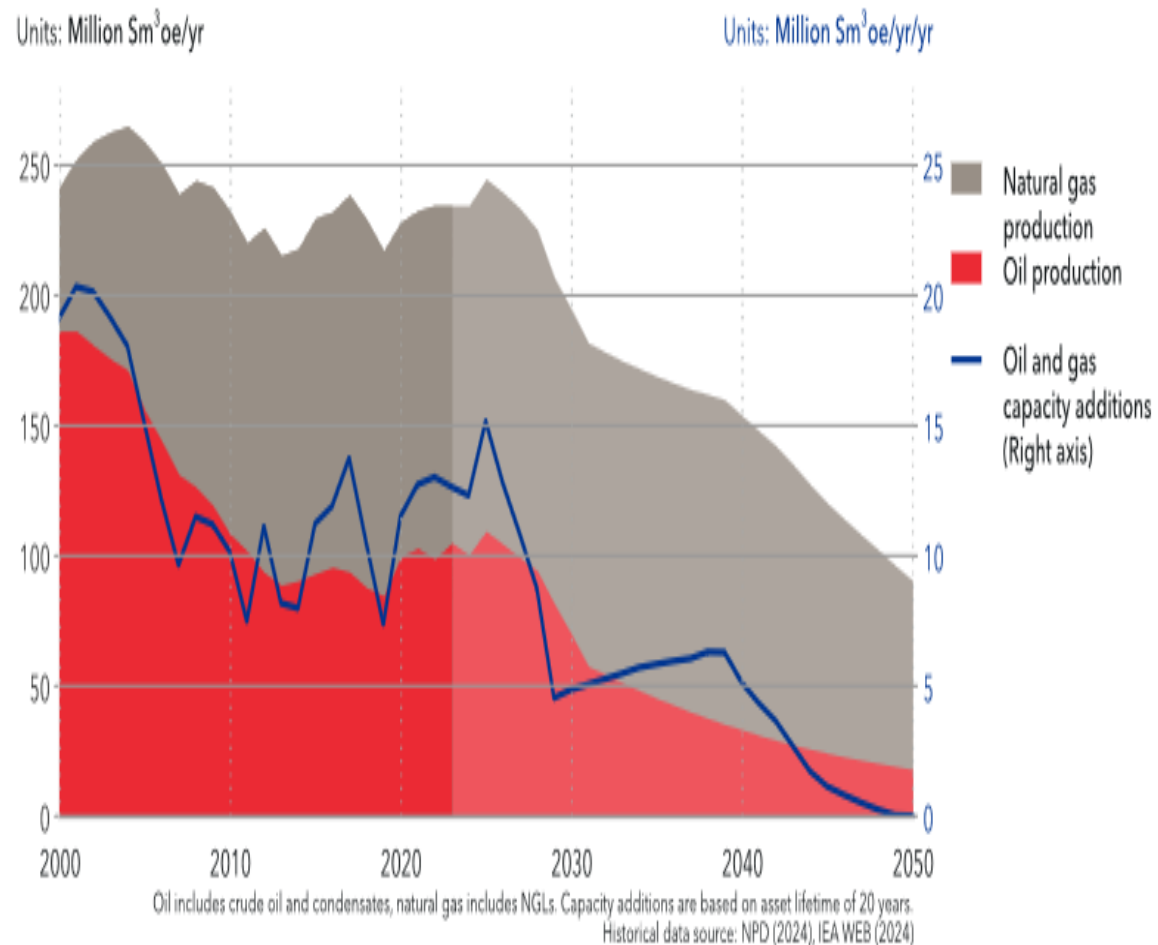


Historical data source: IEA WEB (2024)

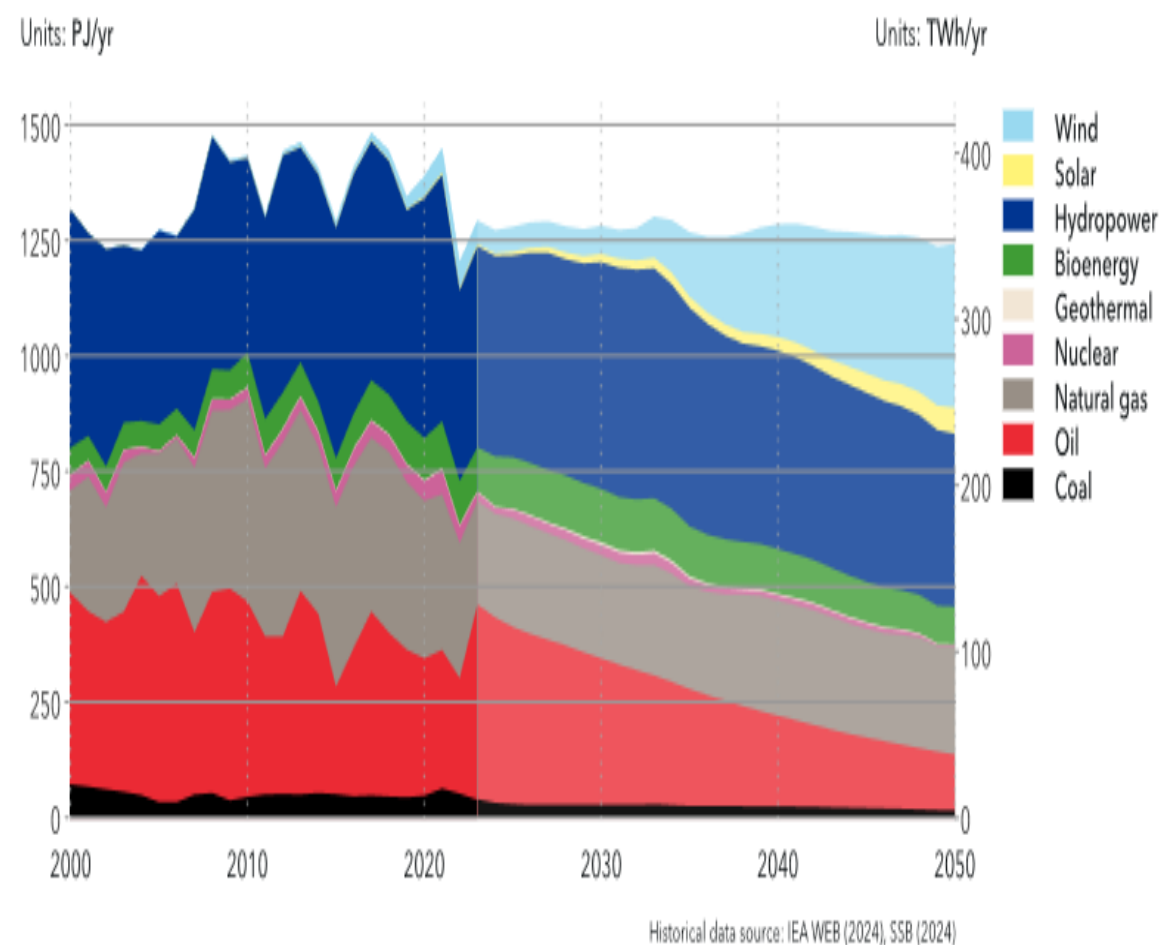
Source: Norway DNV 2024

Norway - O & G Production & Primary Energy Demand

Norway oil and gas production and capacity additions

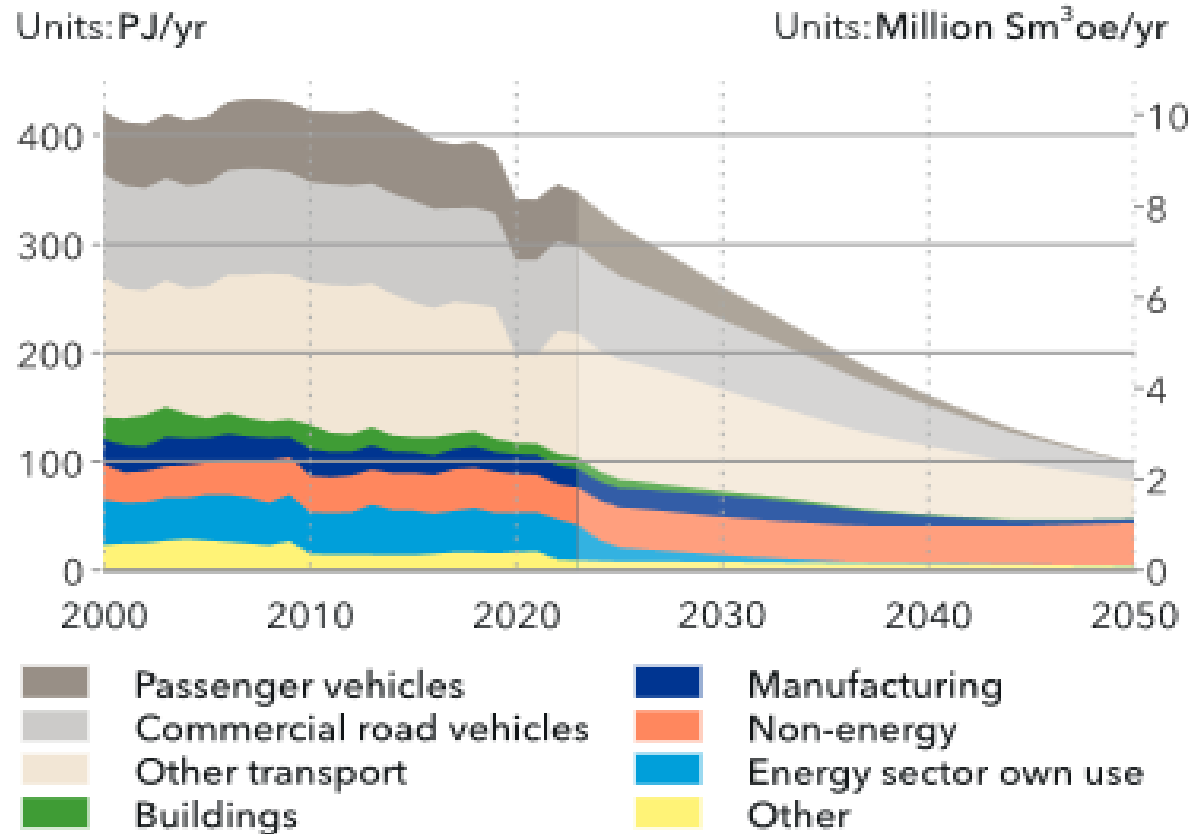


Norway primary energy consumption by source (adjusted for gross electricity trade)



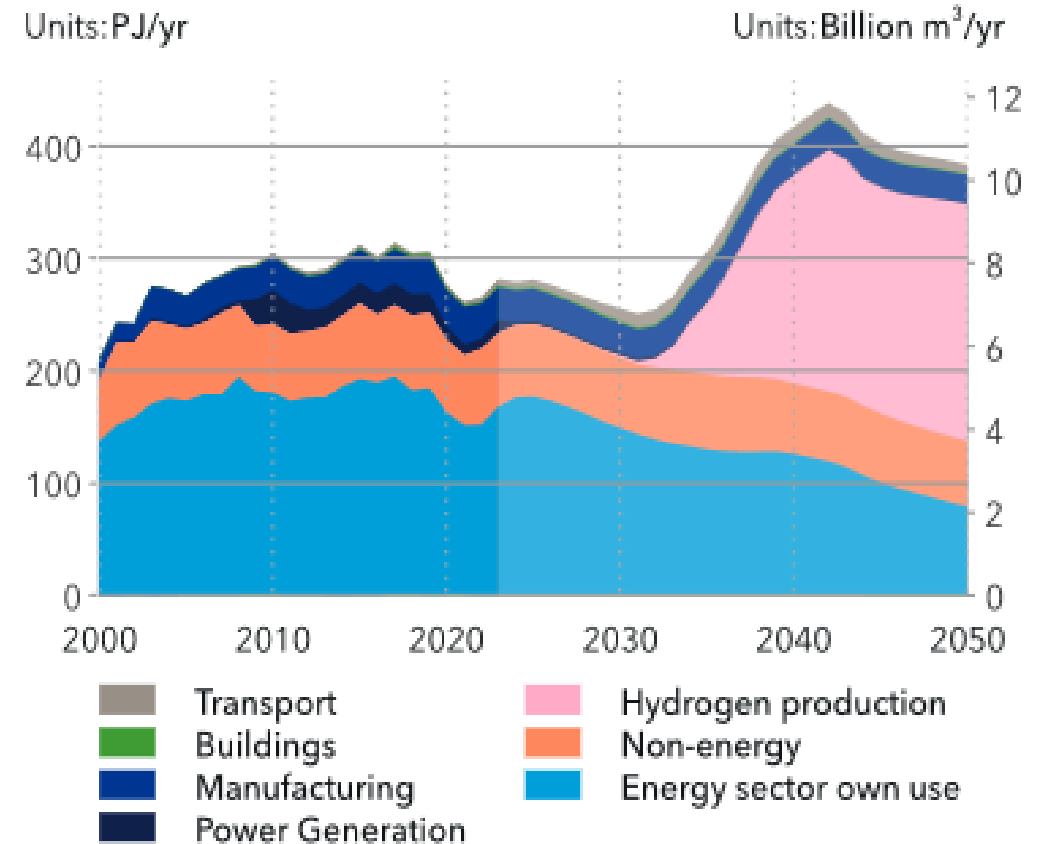
Norway - O & G Demand by Sector

Norway oil demand by sector



Historical data source: NPD (2024), IEA WEB (2024)

Norway natural gas demand by sector



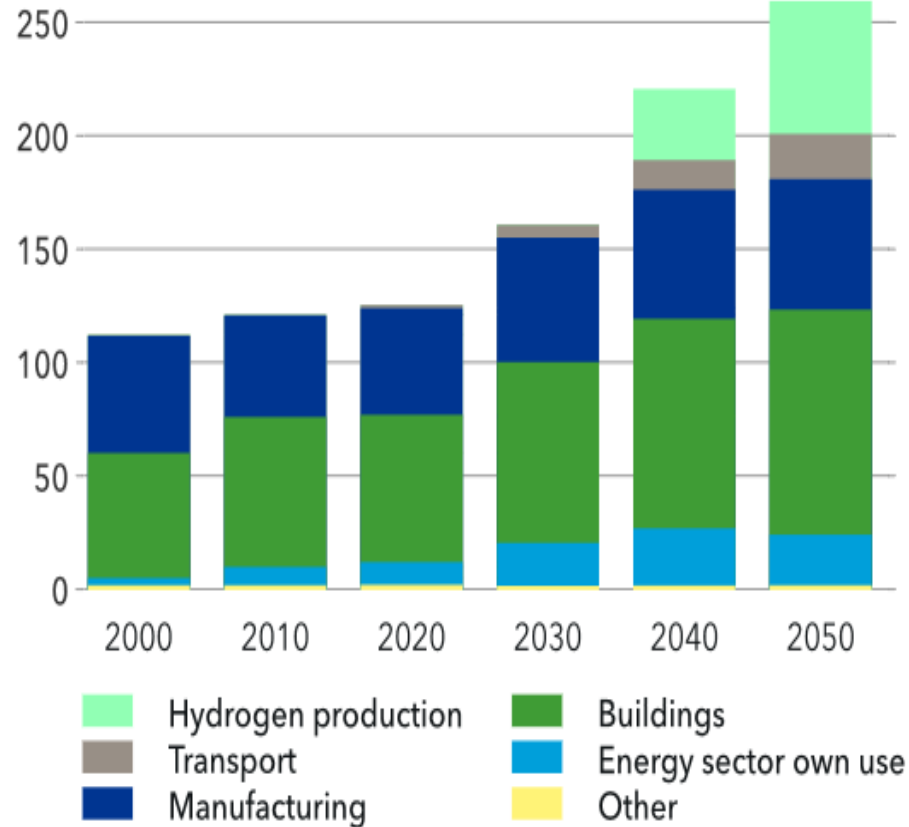
Includes natural gas liquids. Historical data source: IEA WEB (2024), SSB (2024)



Electricity in Norway 2000 - 2050

Norway electricity demand by sector

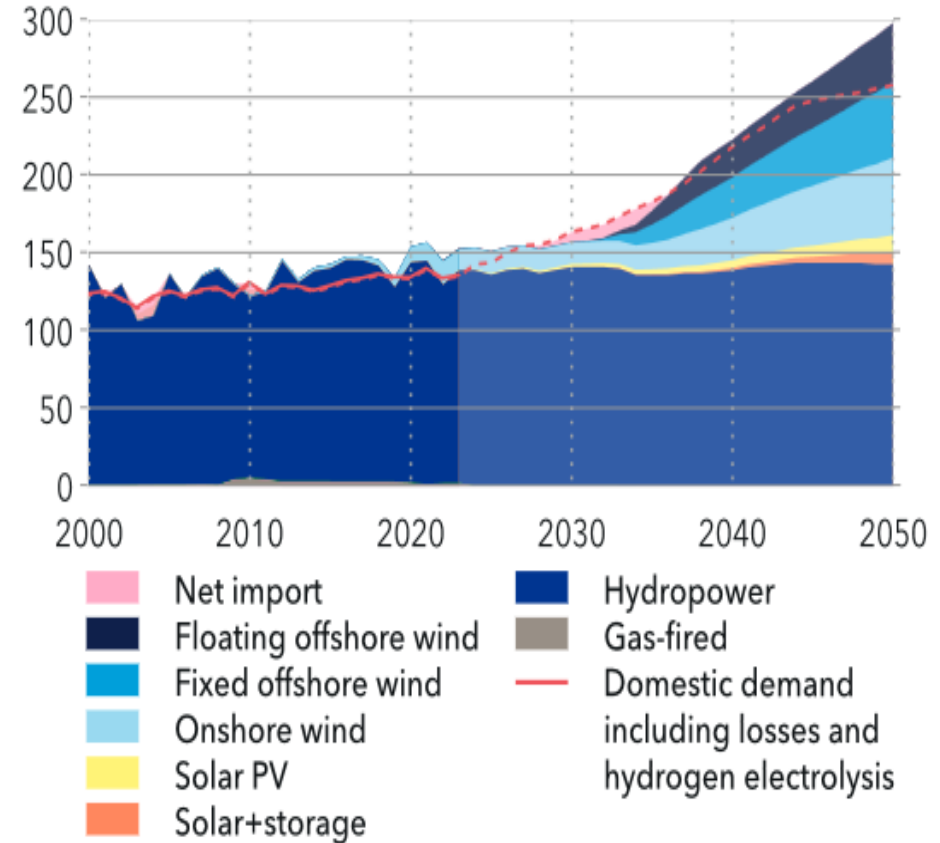
Units: TWh/yr



Historical data source: IEA WEB (2024)

Norway electricity supply by power station and net imports

Units: TWh/yr

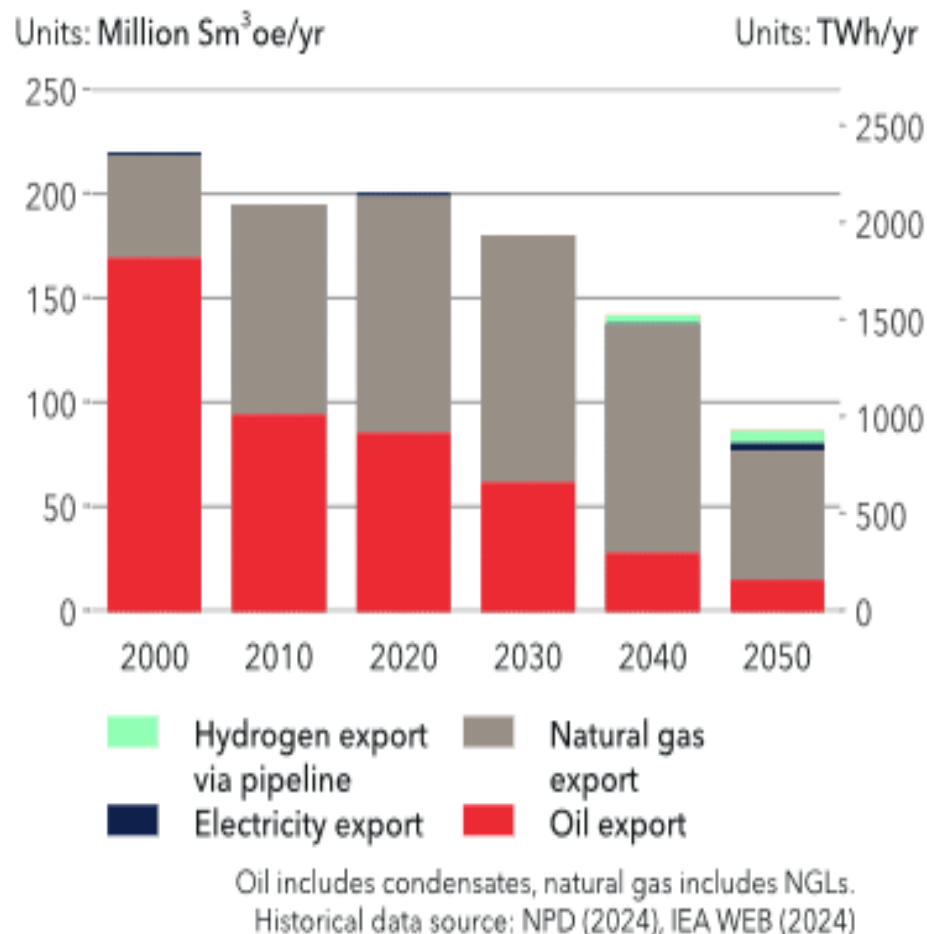


Historical data source: IEA WEB (2024), SSB (2024)

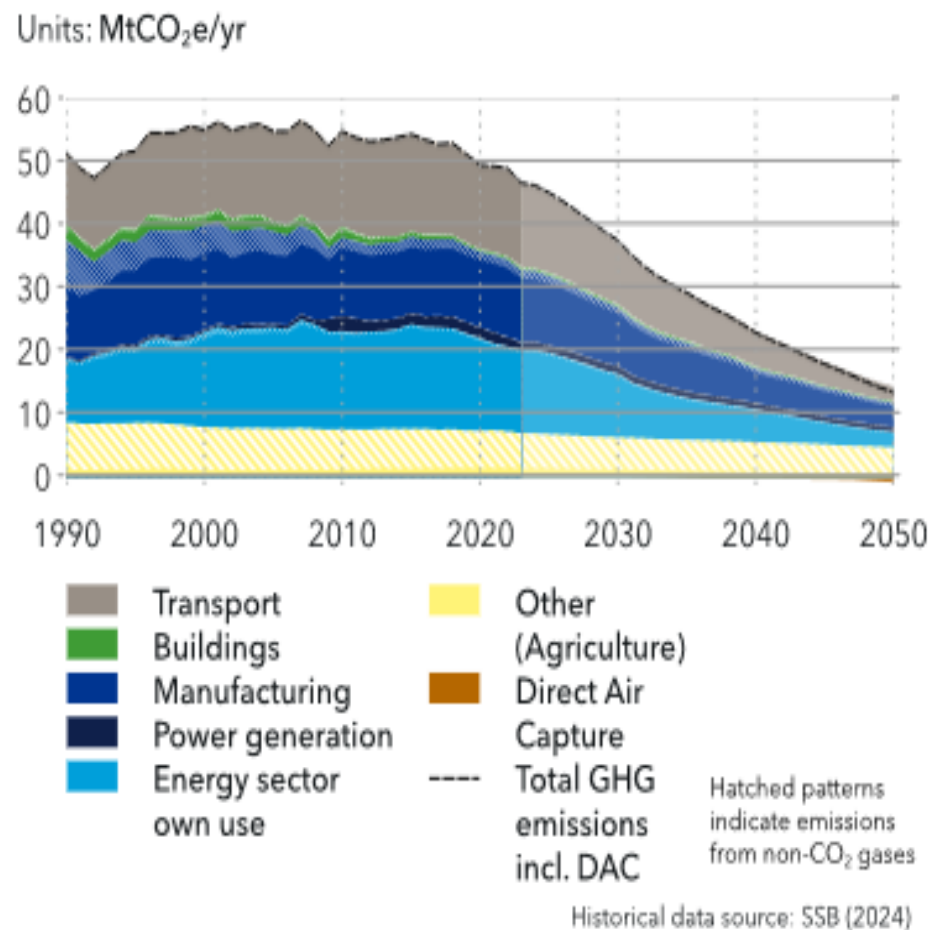


Energy Exports & GGH in Norway 2000 - 2050

Norway energy export



Norway greenhouse gas emissions by sector

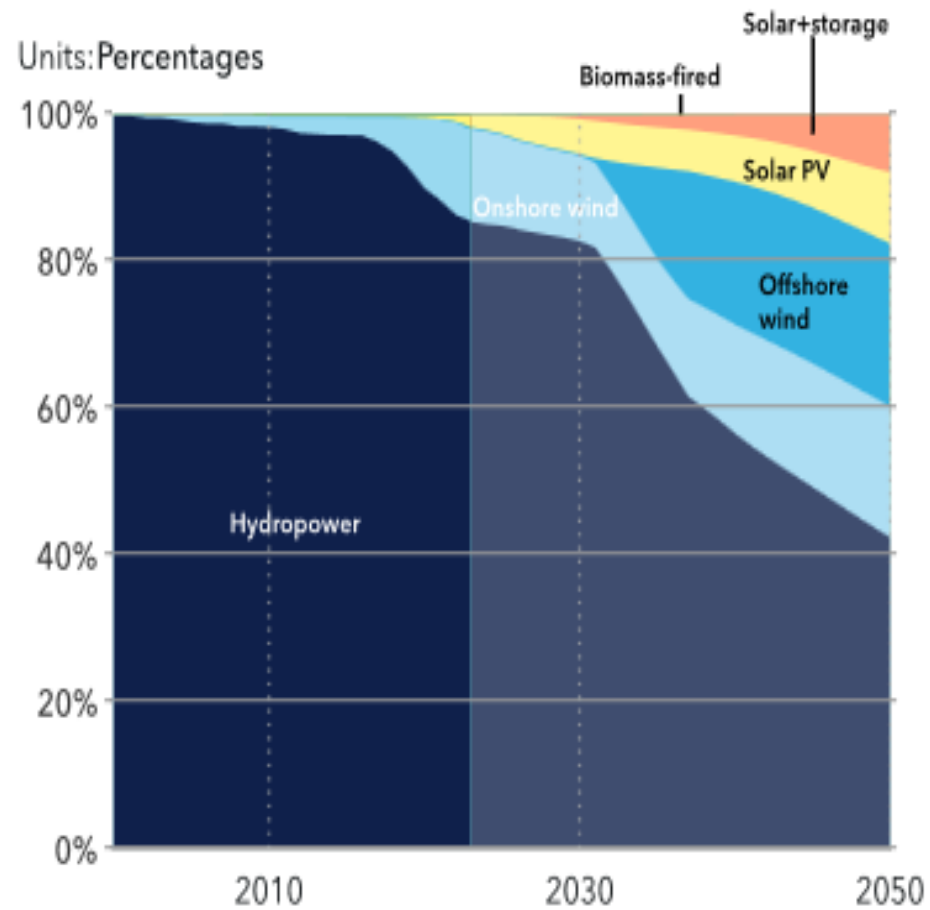


Source: Norway DNV 2024



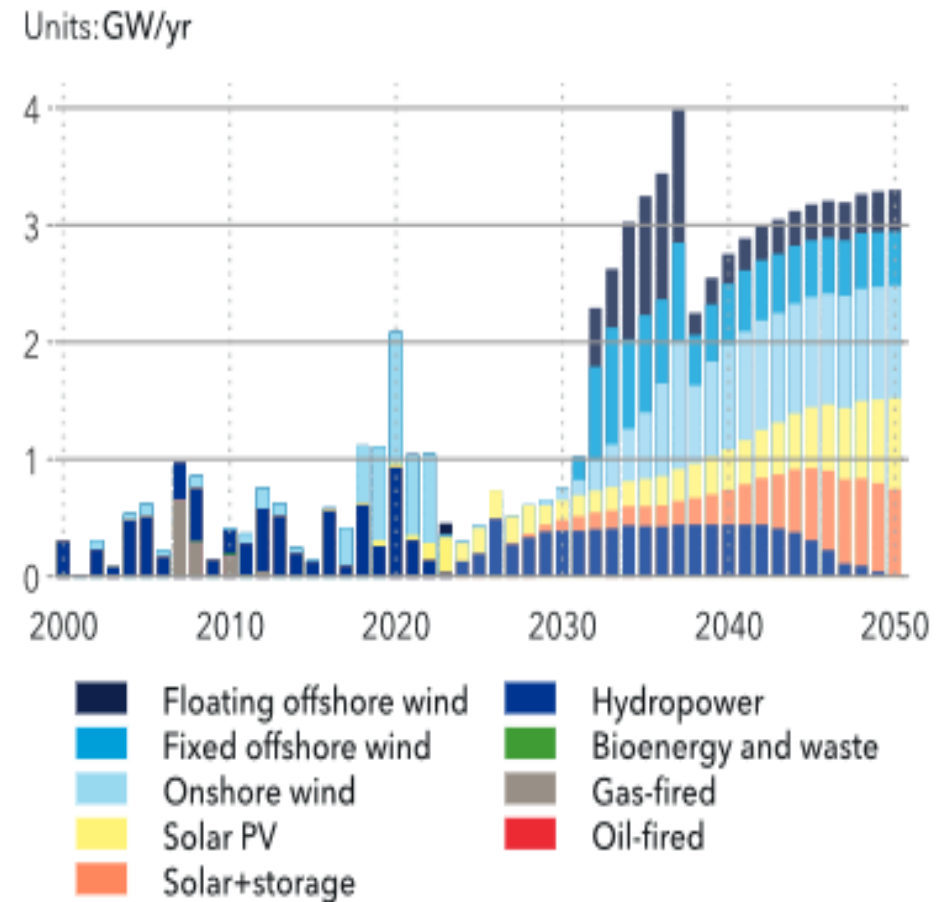
Renewables Installed Capacities in Norway 2000 - 2050

Norway grid and off-grid installed renewable capacity



Historical data source: IEA (2024); GlobalData (2024)

Norway capacity additions becoming operational by power station type



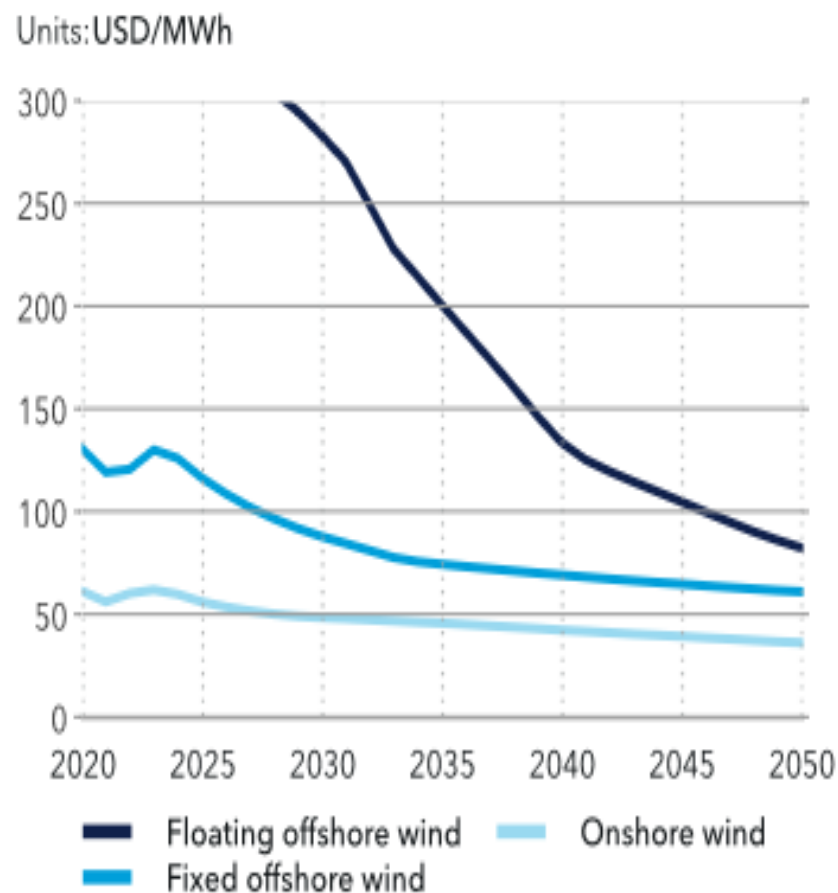
Historical data source: GlobalData (2024)

Source: Norway DNV 2024



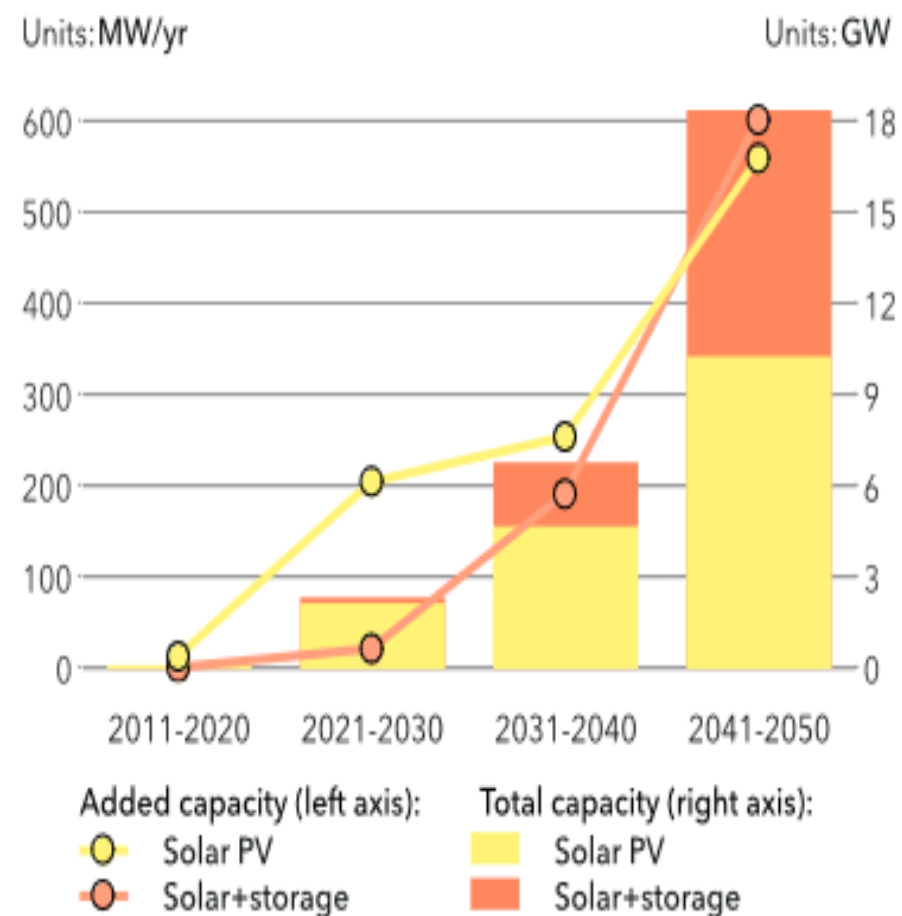
Norway Wind Electricity LCOE & Solar Installed Capacities 2020 - 2050

Norway levelized cost of wind electricity



Historical data source: GlobalData (2024), DNV analysis

Norway solar capacity additions and installed capacity

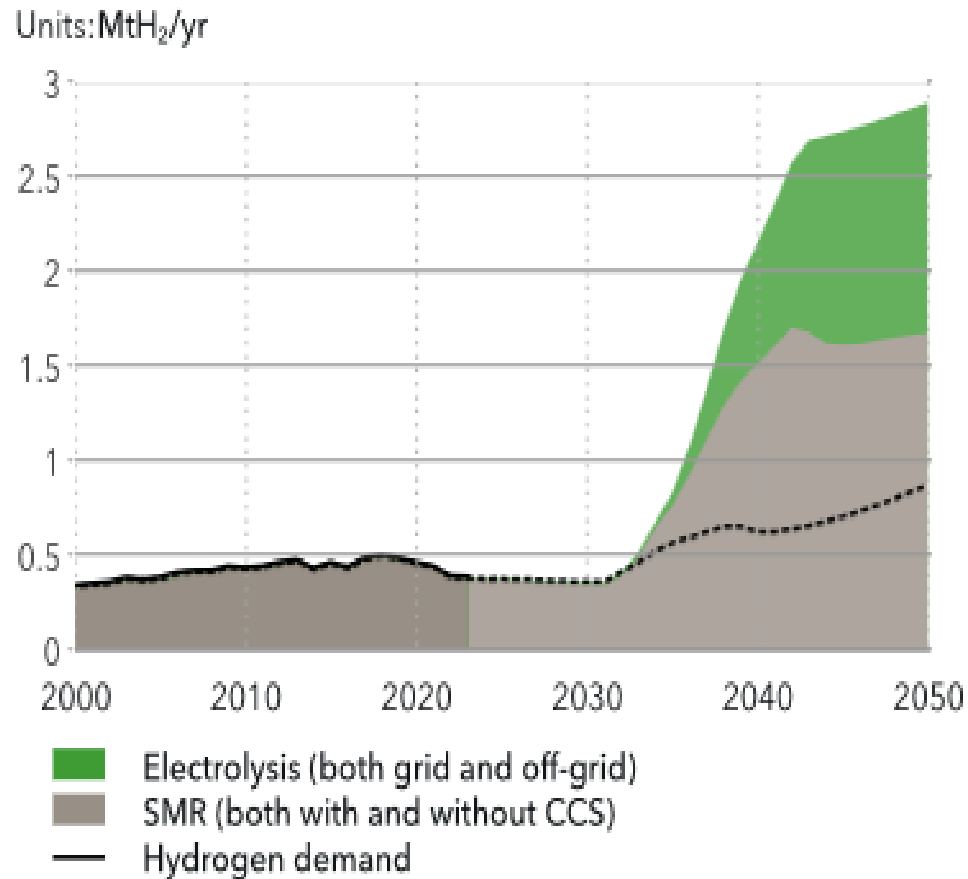


Historical data: GlobalData (2024)



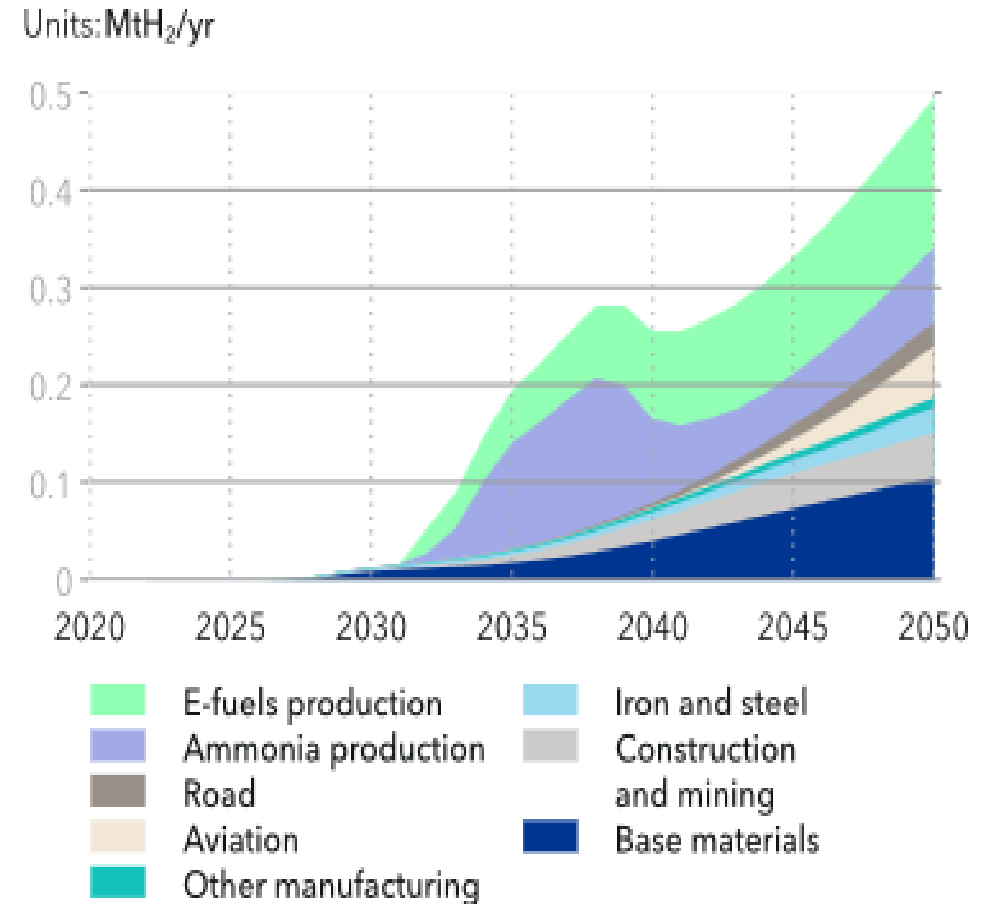
Norway and Hydrogen 2020 - 2050

Norway hydrogen production by production route



Does not include hydrogen use in residual form from industrial processes.
Historical data source: IEA Future of Hydrogen (2019), IEA Global Hydrogen Review (2021).

Norway hydrogen demand as energy carrier by sector

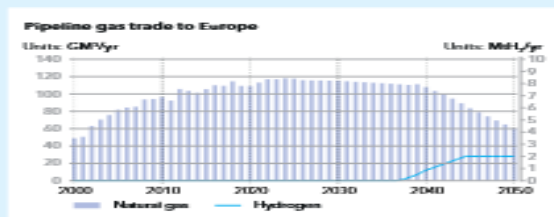
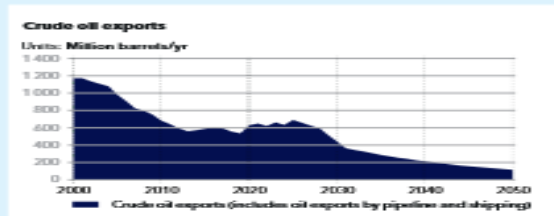
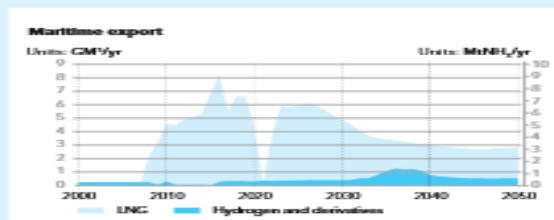


Source: Norway DNV 2024

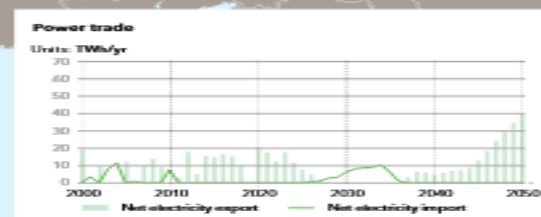
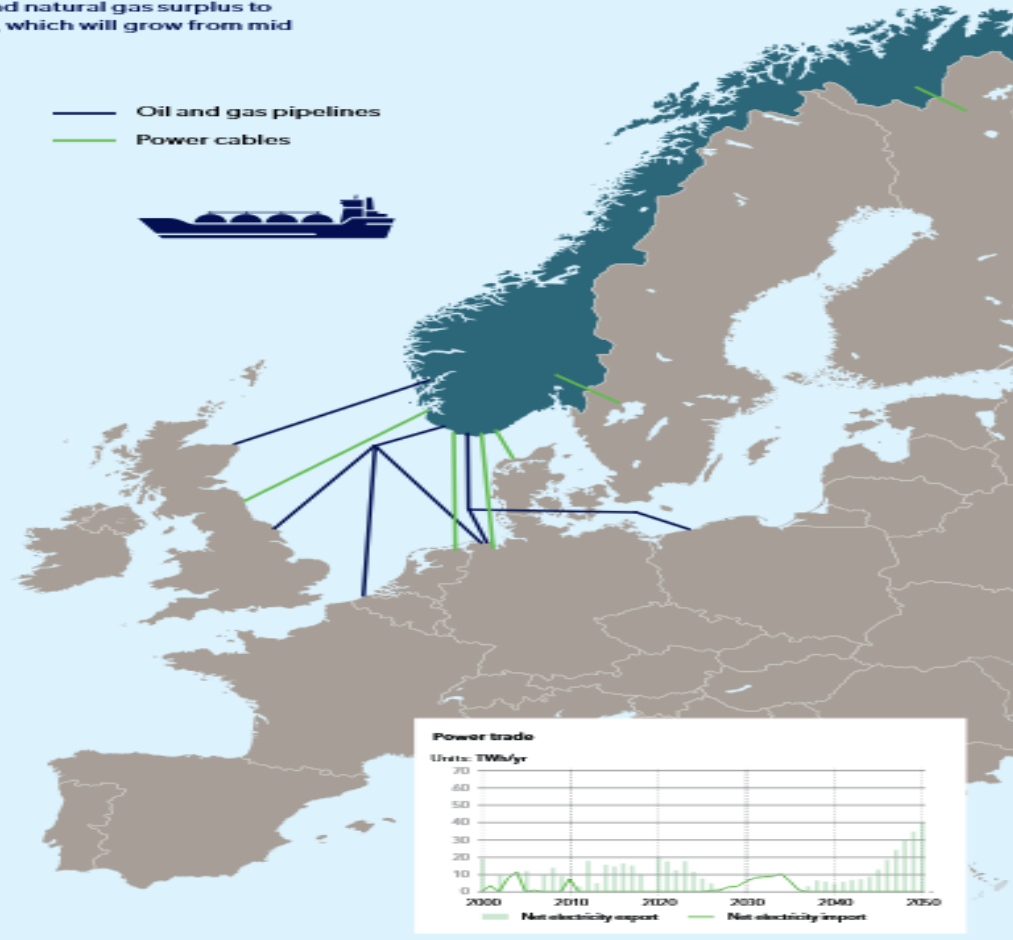
Norway Energy Trade

Energy trade

By 2050, Norway's oil export will be 15% of today's level. Natural gas exports will be halved compared with today. A growing share of energy exports will be diverted to electricity and hydrogen. Electricity production will eventually grow faster than domestic demand and Norway will export 40 TWh/yr of electricity by 2050. In addition, Norway will use parts of the power and natural gas surplus to convert it to hydrogen and hydrogen derivatives, which will grow from mid 2030s to 2 Mth-I₂/yr by 2050.



— Oil and gas pipelines
— Power cables



Oil and gas pipelines, power connectors and ship location are simplified



Norway Objective: Zero Carbon

- ◆ Generation of Electricity (40 GW,155 MWh) : 92% Hydro, 2% Thermal, 6% Wind (65 wind farms)
- ◆ 1st oil producer in Europe (2 Mb/d)
- ◆ 5,4 million inhabitants. Sovereign fund = 1500 B\$ mid 2023.
- ◆ Objective: To become a Clean Tech. Leader.
- ◆ Development of Biomass and Wind Offshore.
- ◆ Objective CO₂ emissions: - 50% in 2030 vs 1990.
- ◆ Development of electrical vehicles.
- ◆ Development of Carbon, Capture and Storage (CCS) technology, Technological Center at Mongstad.
- ◆ Development of floating wind turbines (electricity generation for oil & gas platforms and for export – US and Japan)
- ◆ Reinforcement of electrical network to export electricity to Sweden.



1-2

Trends/Perspectives

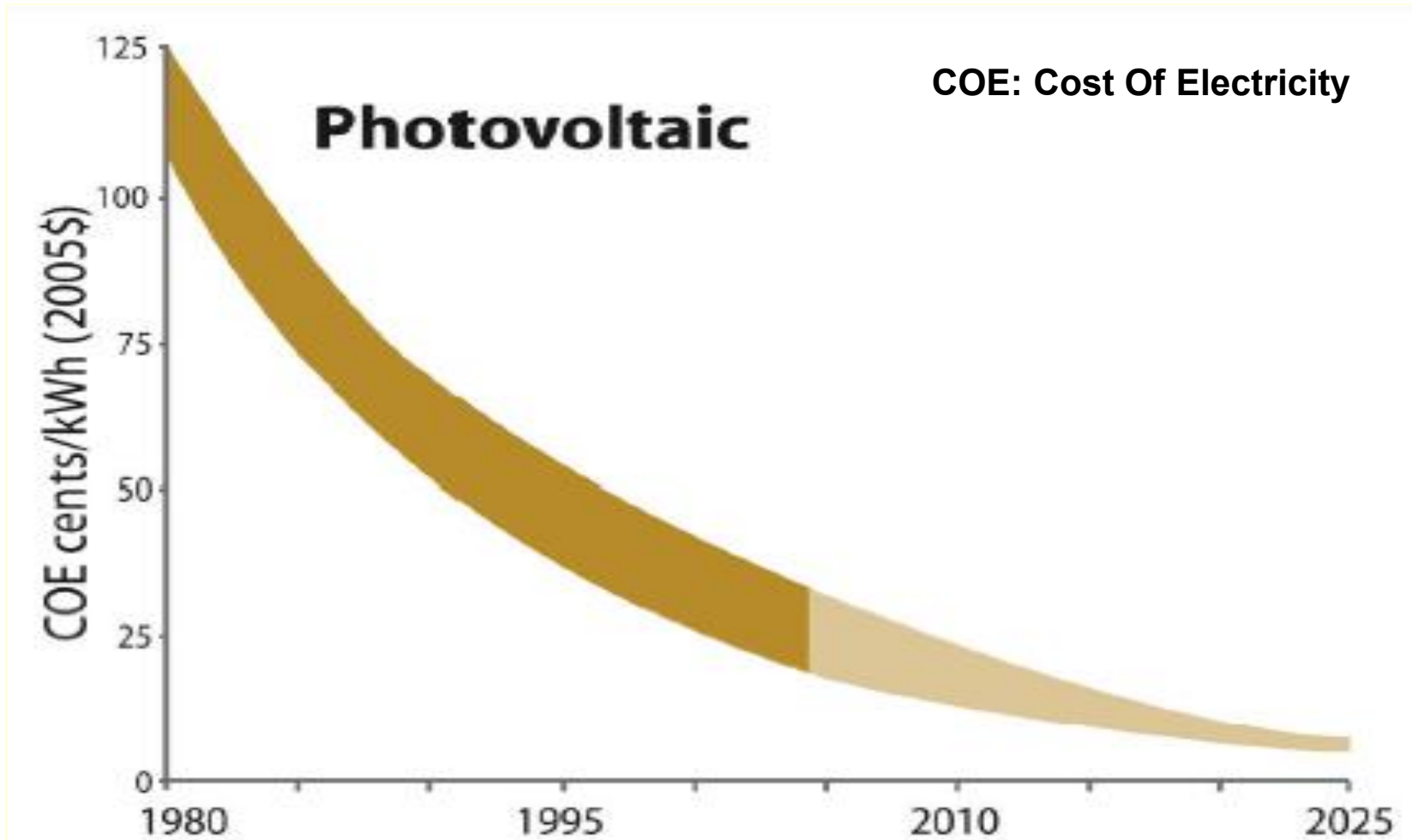


**Production Costs of New Renewable Energies
are declining rapidly which should improve their
competitiveness on the long term**

R&D and Learning Curve
 **Costs reductions**



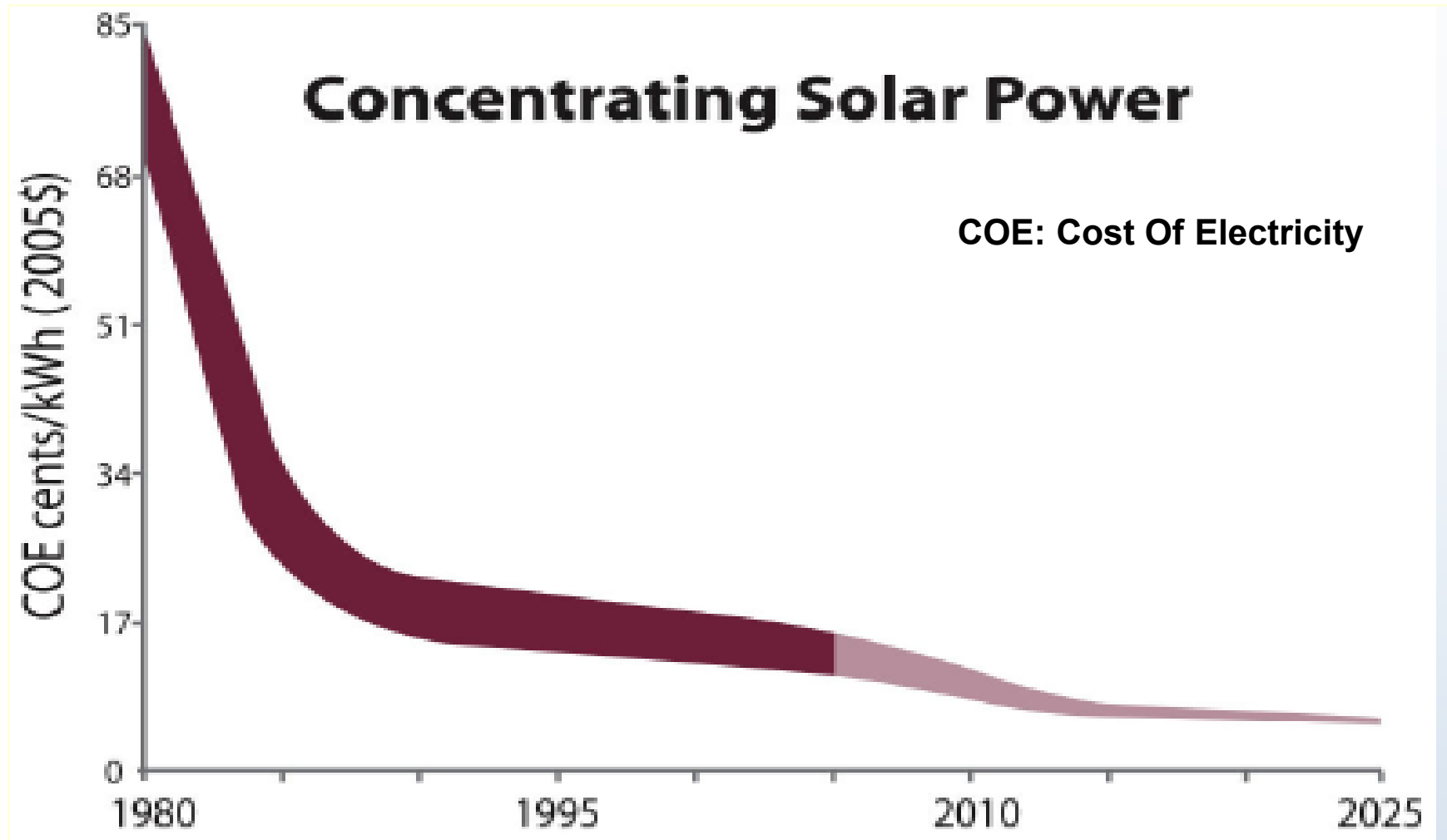
Trends in Renewable Energy costs curve 2005 Vision



Source: EAO/NREL (US Department of Energy)



Trends in Renewable Energy costs curve 2005 Vision

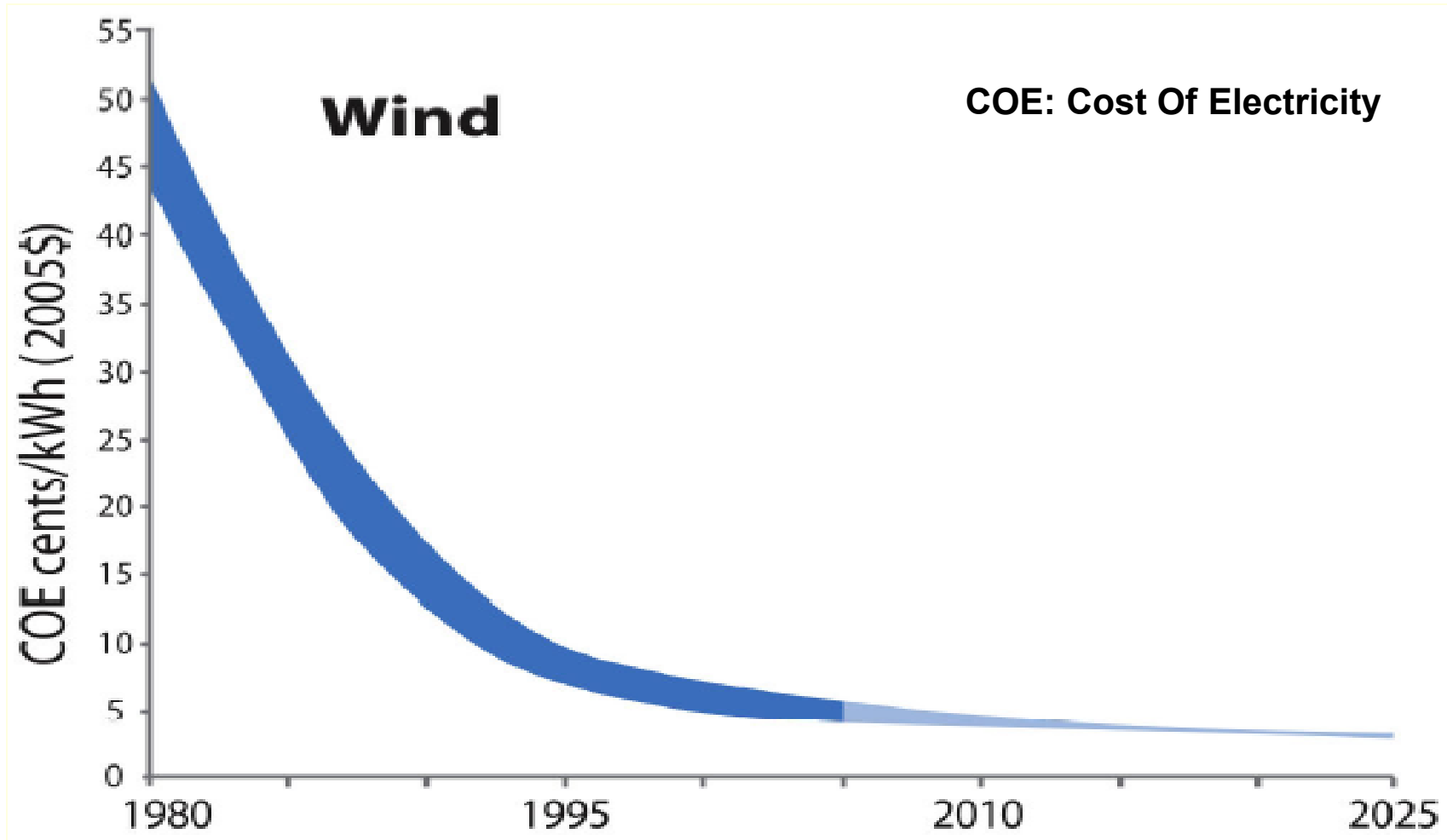


Source: EAO/NREL (US Department of Energy)

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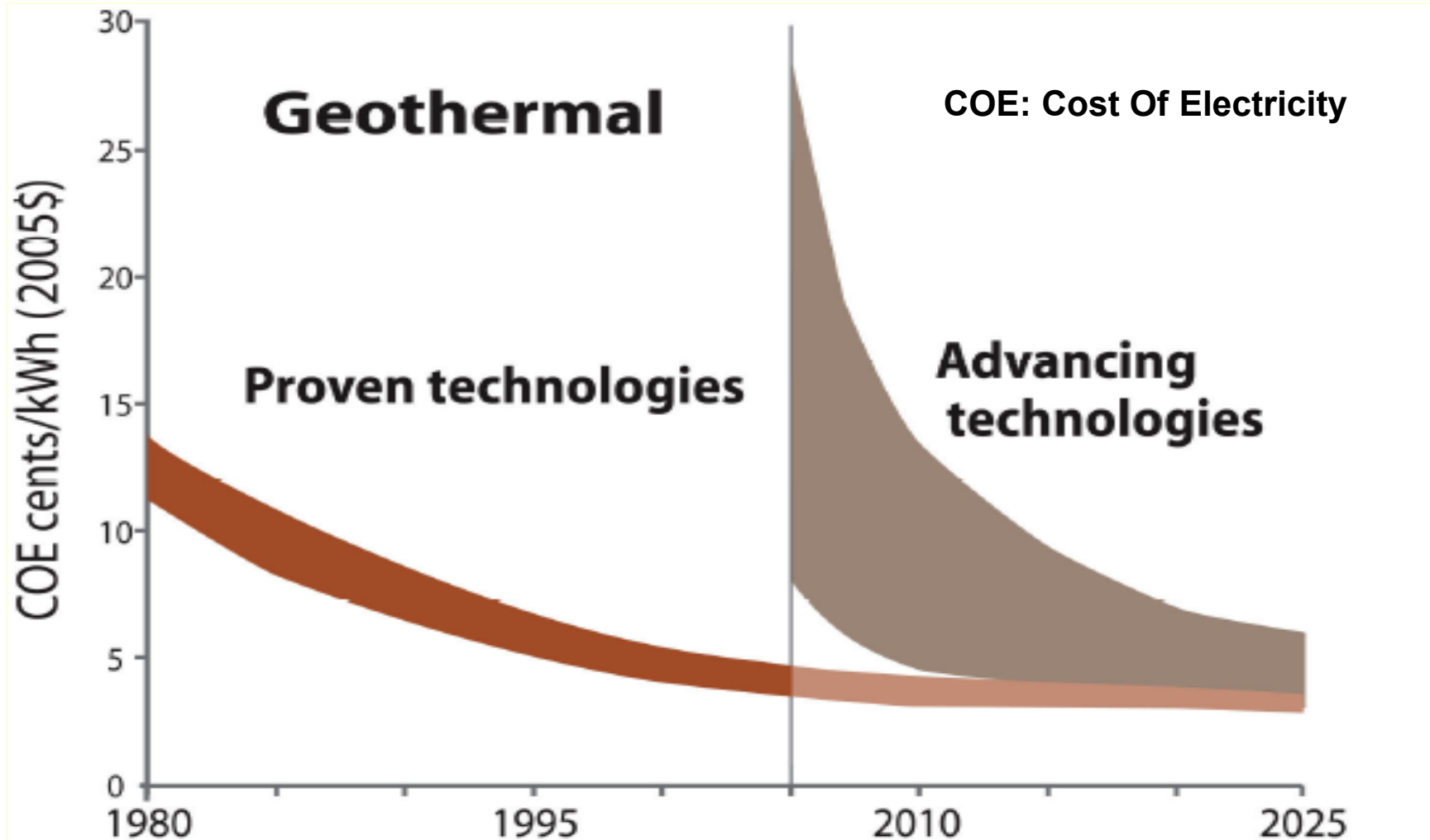
Trends in Renewable Energy costs curve 2005 Vision



Source: EAO/NREL (US Department of Energy)
77



Trends in Renewable Energy costs curve 2005 Vision



Source: EAO/NREL (US Department of Energy)
78



Costs Reduction (Total installed costs) from 2010 to 2020 (World Average)



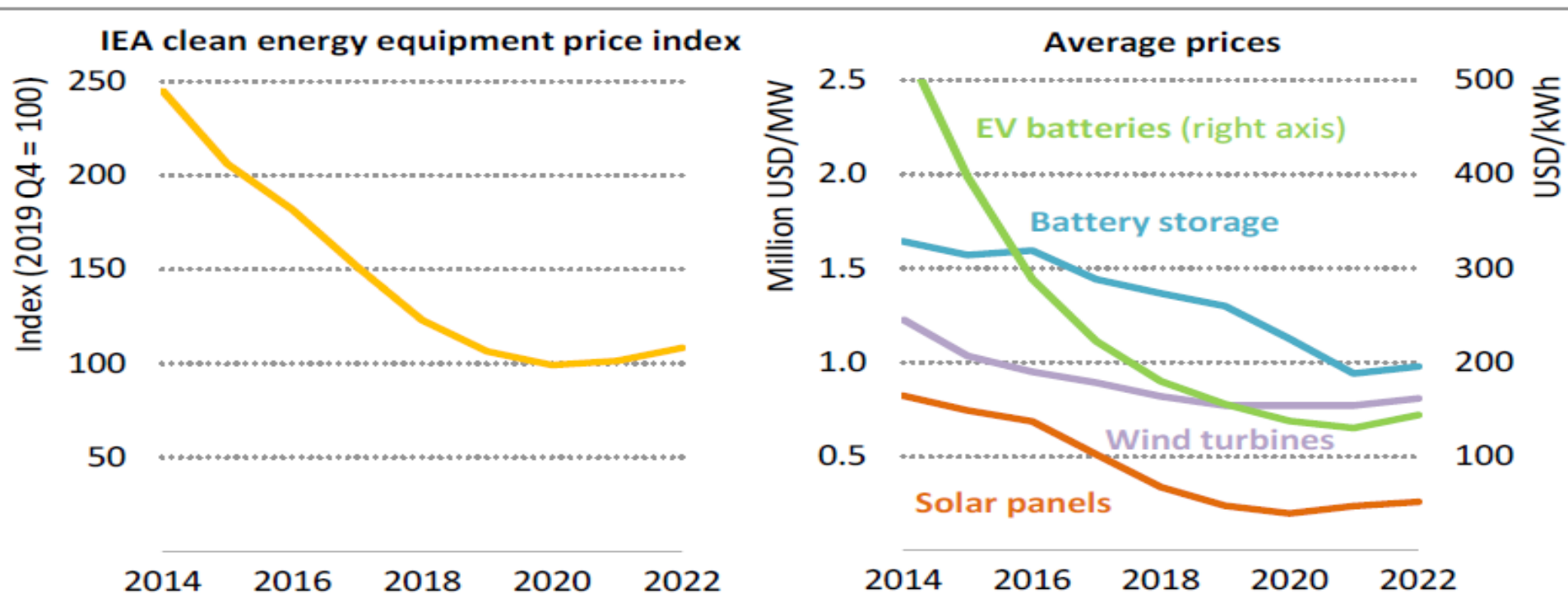
- 30% for Wind



- 80% for Photovoltaic



Average Global Costs Reduction 2014 - 2022 for Selected Technologies



IEA. CC BY 4.0.

Clean energy technology costs edged higher in 2022, but pressures are easing in 2023 and mature clean technologies remain very cost competitive in today's fuel price setting

Notes: Q4 = fourth-quarter; MW = megawatt; kWh = kilowatt-hour. The IEA clean energy equipment price index tracks price movements of a fixed basket of equipment products that are central to the clean energy transition, weighted according to their share of global average annual investment in 2020-2022: solar PV modules (48%), wind turbines (36%), EV batteries (13%) and utility-scale batteries (3%). Prices are tracked on a quarterly basis with 2019 Q4 defined as 100. Nominal prices.

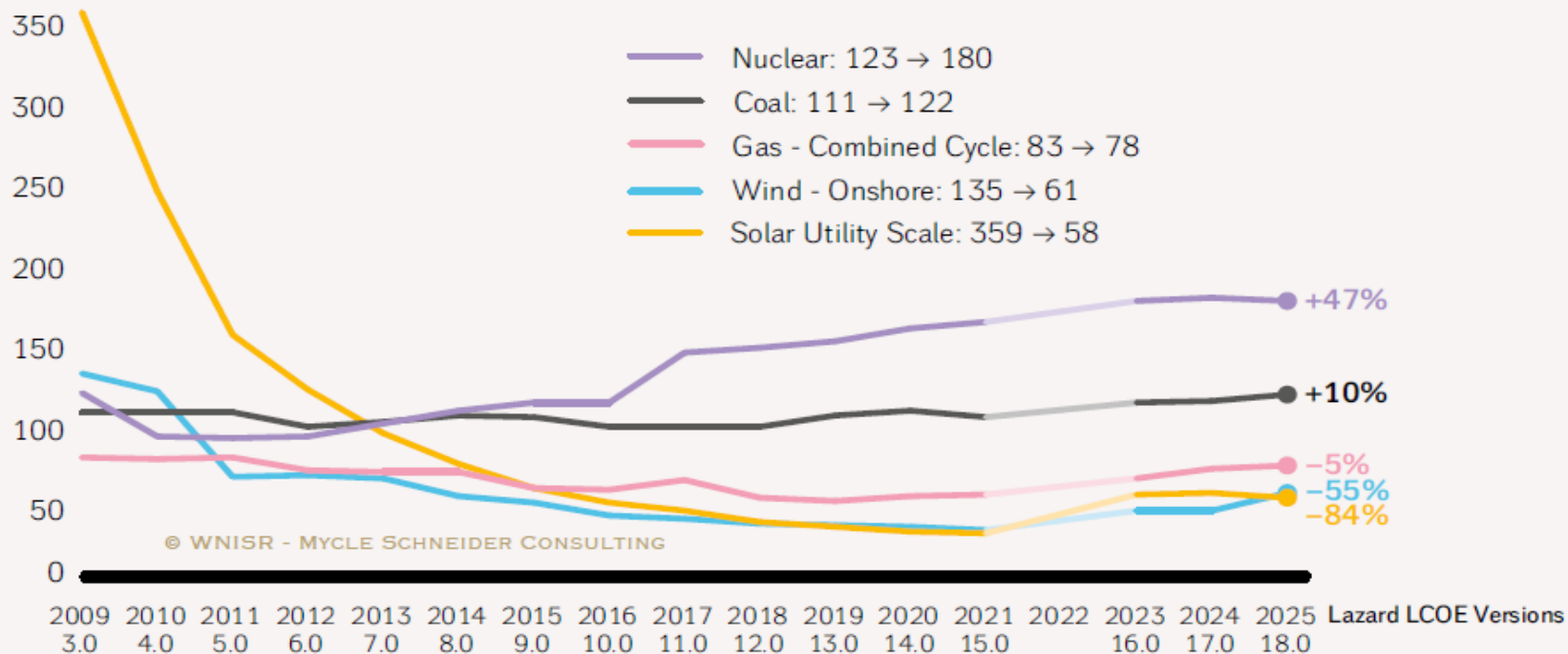
Source: IEA WEO 2023



Average Global Costs Reduction 2009 - 2025 for Selected Technologies

Selected Historical Mean Costs by Technology

LCOE values in US\$/MWh *



* Reflects total decrease in mean LCOE since Lazard's LCOE VERSION 3.0 in 2009.

Source: Lazard Estimates, 2025

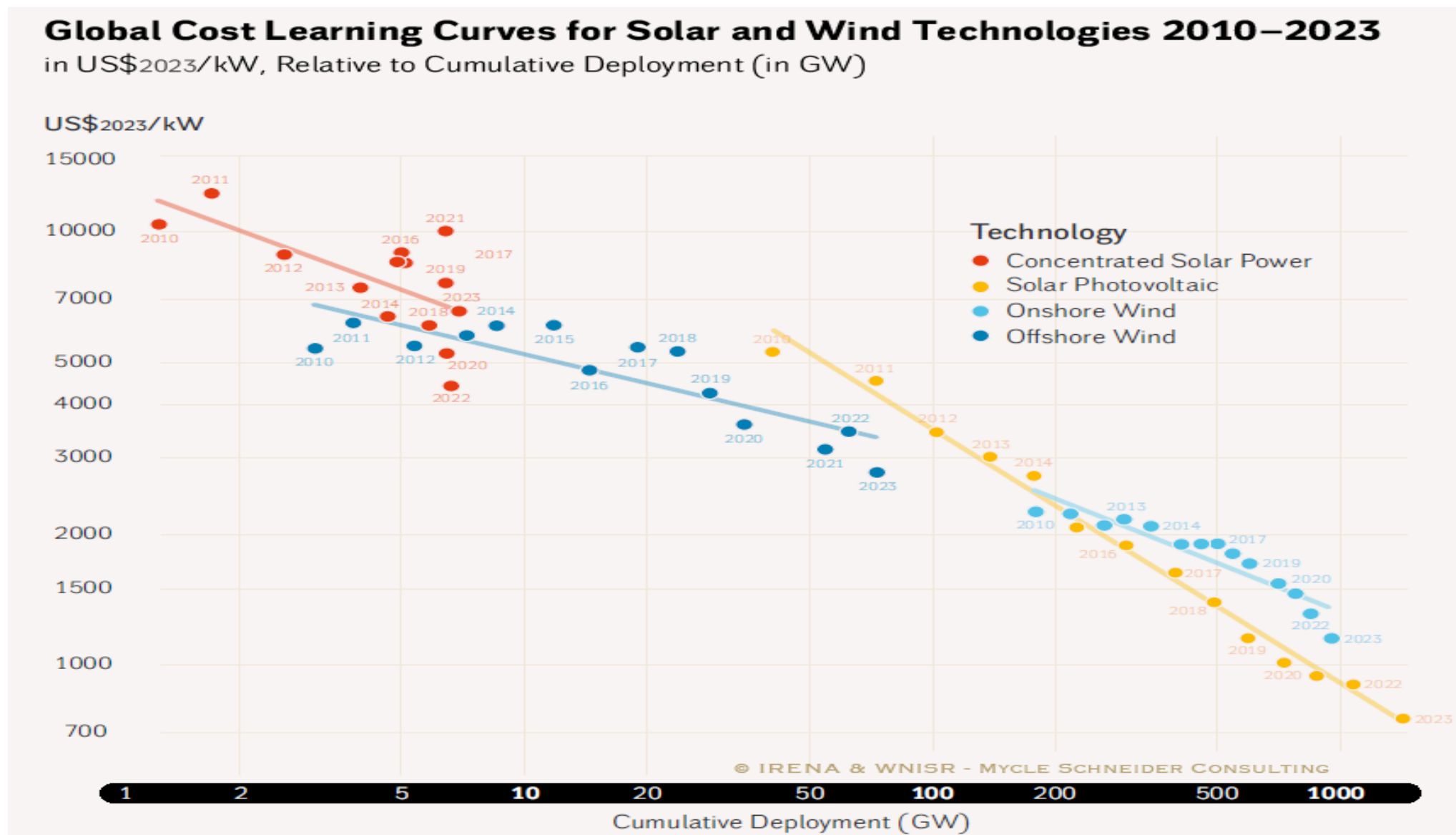
Notes: **LCOE**: Levelized Cost of Energy

*This graph reflects the average unsubsidized LCOE values in current dollars (not adjusted for inflation) for a given version of LCOE study. It primarily relates to the North American energy landscape but reflects broader, global cost developments.

Source: Mycle Schneider WNISR 2025



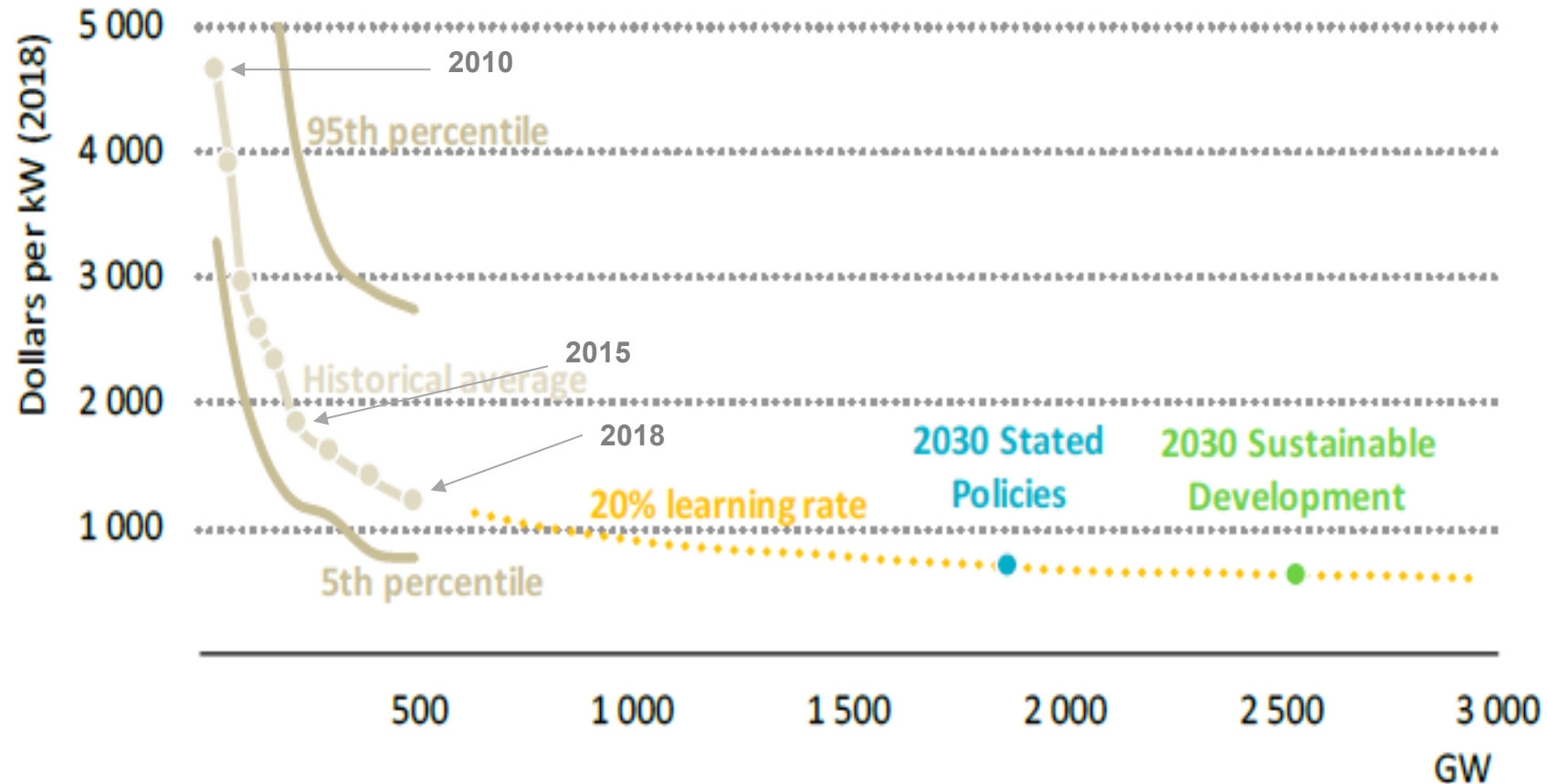
Average Global Costs Reduction 2010 - 2023 for Selected Technologies



Source: Mycle Schneider WNISR 2025/IRENA 2024

Reminder - Trends in Solar Energy costs curve

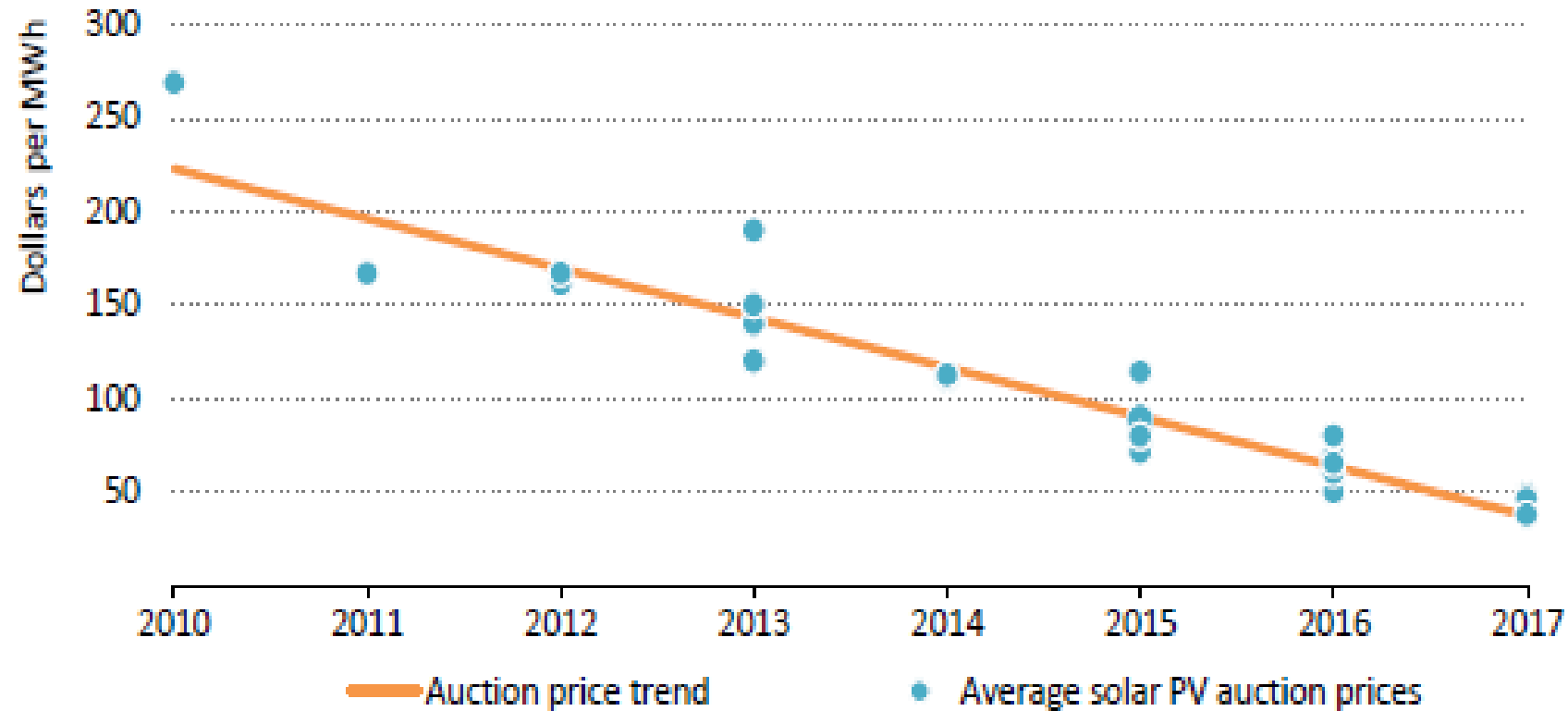
Capex/kW are decreasing substantially



Policies drive more unit additions in the Sustainable Development Scenario, leading to lower costs that approach the expected limits of current technology



Reminder - Auction Results for Solar PV in India From 250 \$/MWh in 2010 to 50 \$/MWh in 2017

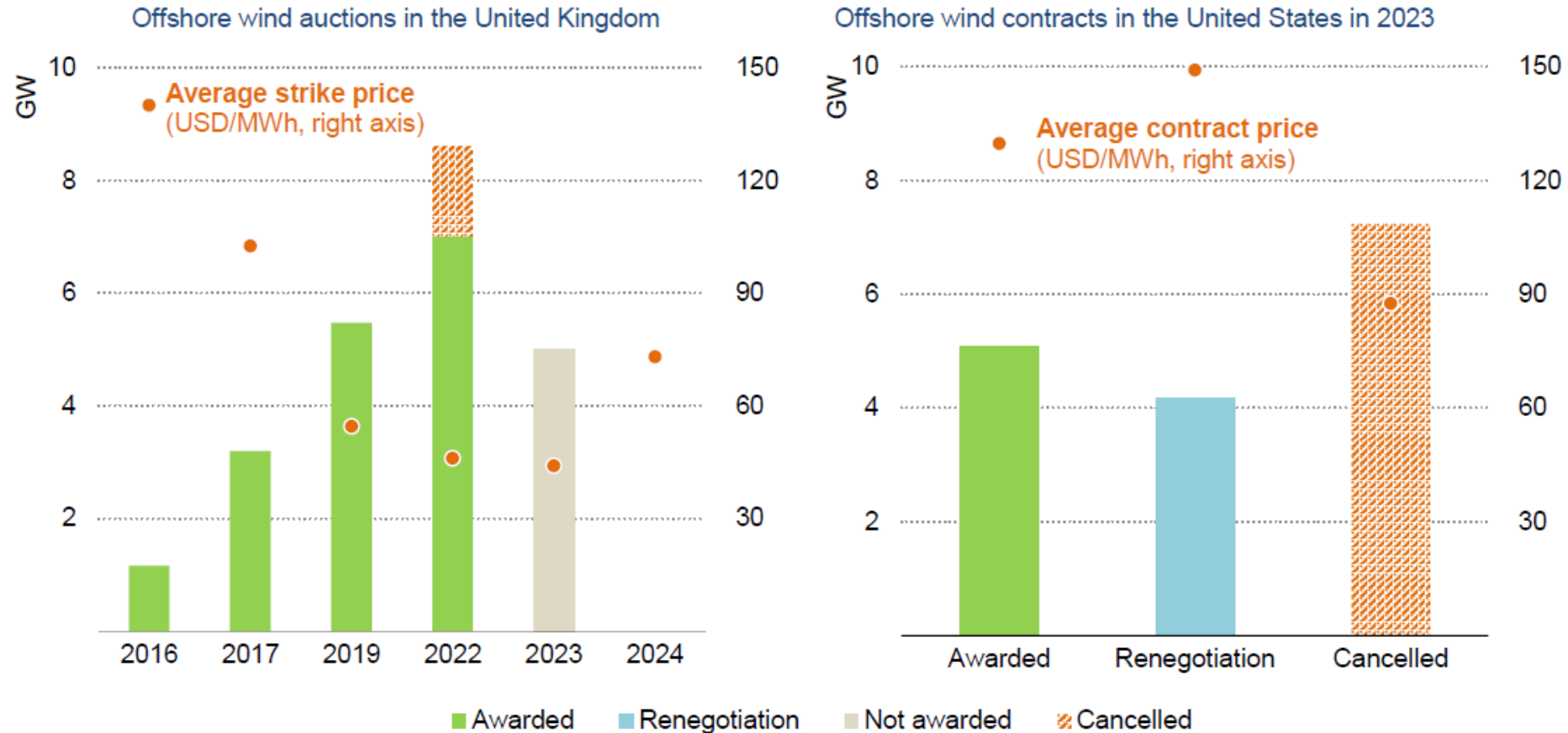


*Solar PV auction prices are falling fast in India,
narrowing the cost gap with other technologies*



Auction Results for Offshore Wind auctions in UK & US

From 140 \$/MWh in 2016 to 45 \$/MWh in 2023. Governments adjust Energy purchase price
Contracts profitability can be at stake.



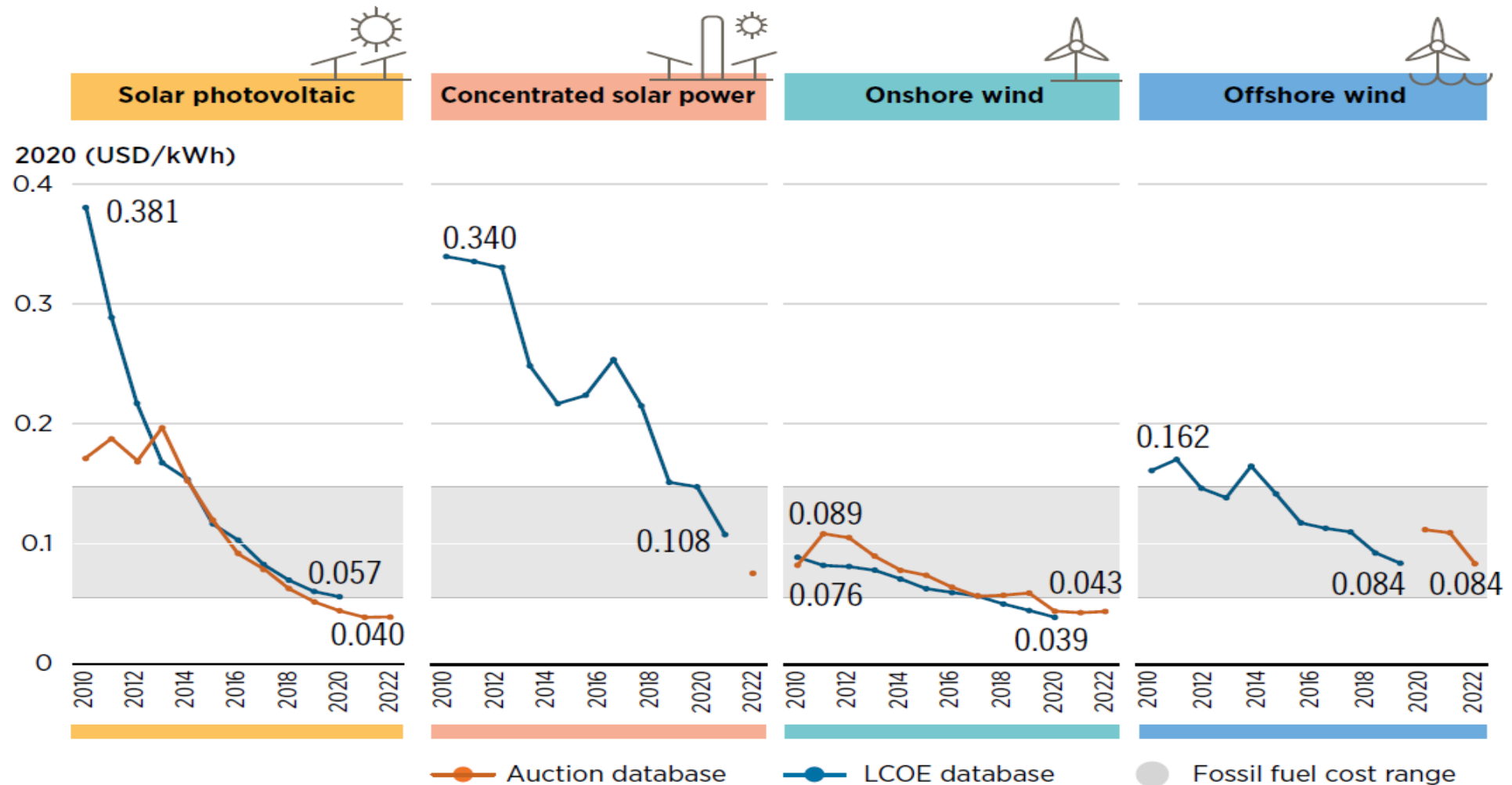
IEA. CC BY 4.0.

Note: UK average strike and US average contract prices are expressed in 2023 USD.

Source: IEA calculations based on UK Department of Energy and Change and company reports.



Average Global Costs Reduction 2010 - 2022 for Selected Technologies



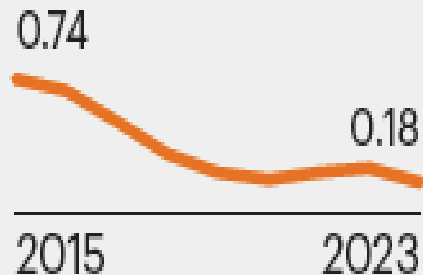
Average Global Costs Reduction 2015 - 2023 for Selected Technologies

Falling clean energy prices

Recent years have seen large overall price reductions for many clean energy technologies.

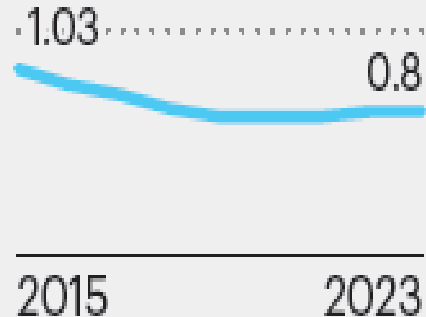
Solar panels

Million USD per MW



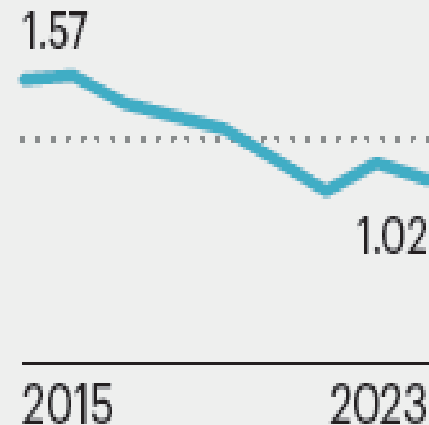
Wind turbines

Million USD per MW



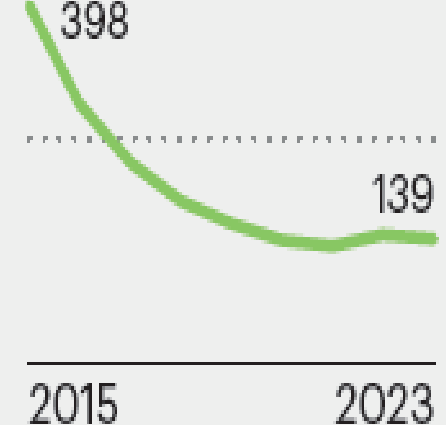
Battery storage

Million USD per MW

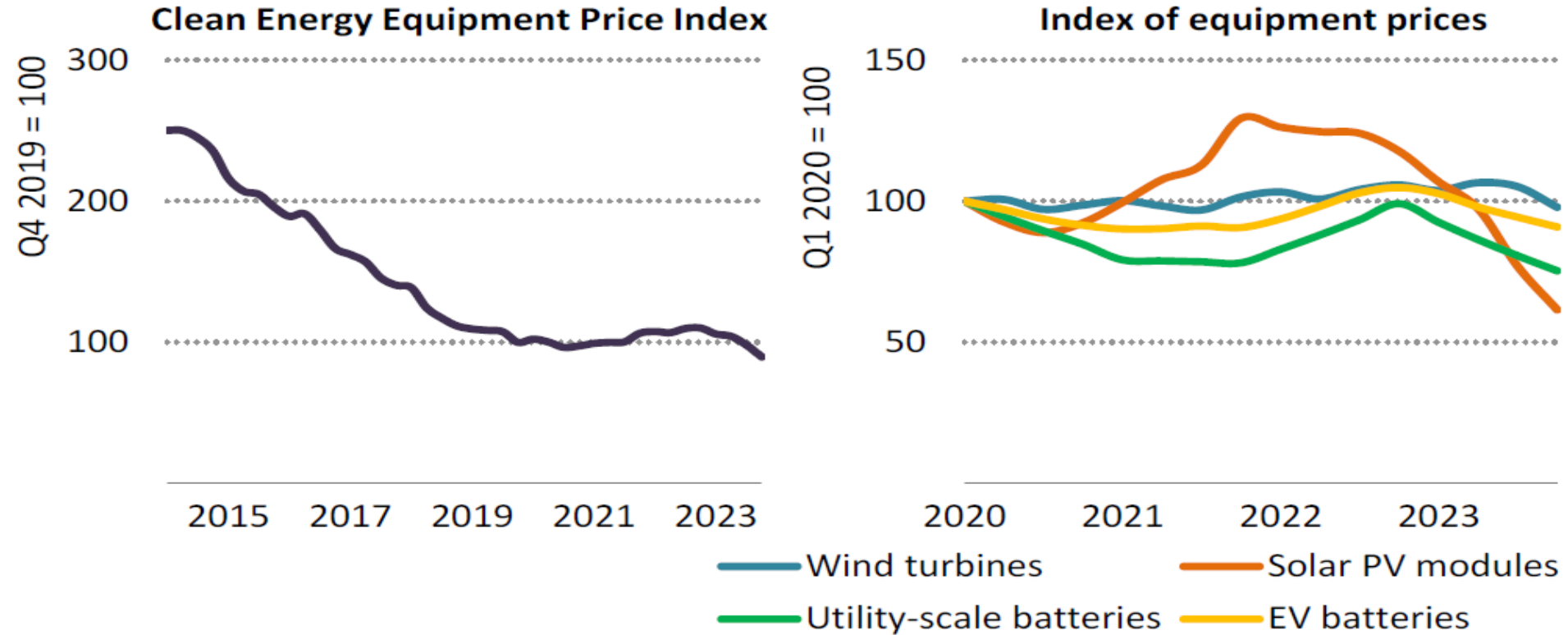


EV batteries

USD per kWh



Average Global Costs Reduction 2014 - 2023 for Clean Energy Technologies – End of a declining trend?



IEA. CC BY 4.0.

The price of key clean energy equipment increased in 2021 and 2022 after years of steady declines

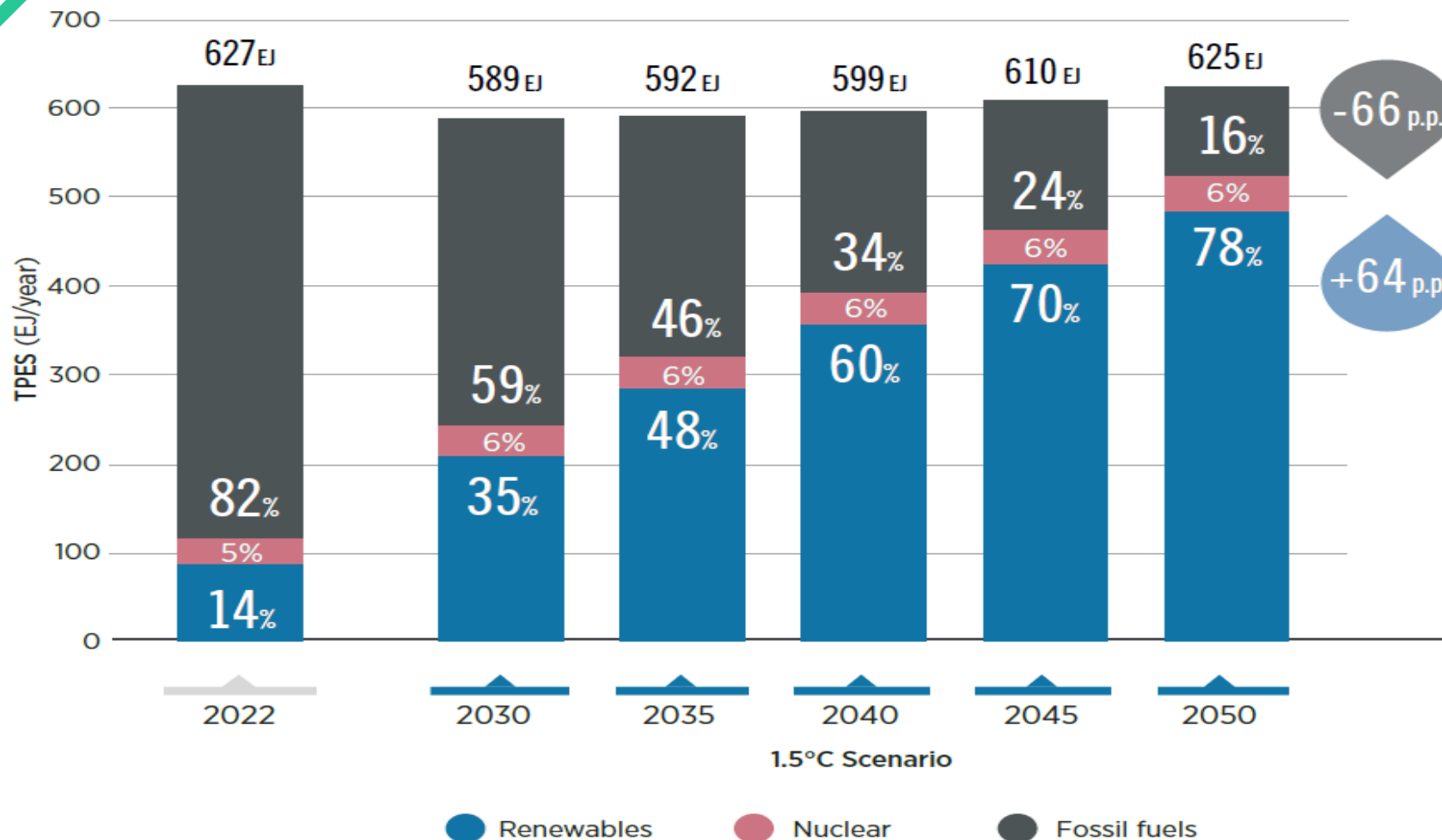
Source: IEA Strategies for Affordable and Fair Clean Energy Transition - June 2024



NZE



Total Primary Energy Consumption 1,5°C Scenario by IRENA 2024



Source: IRENA World Energy Transition Outlook 2024

Nota: IRENA 1,5 °C scenario is slightly different from IEA NZE scenario



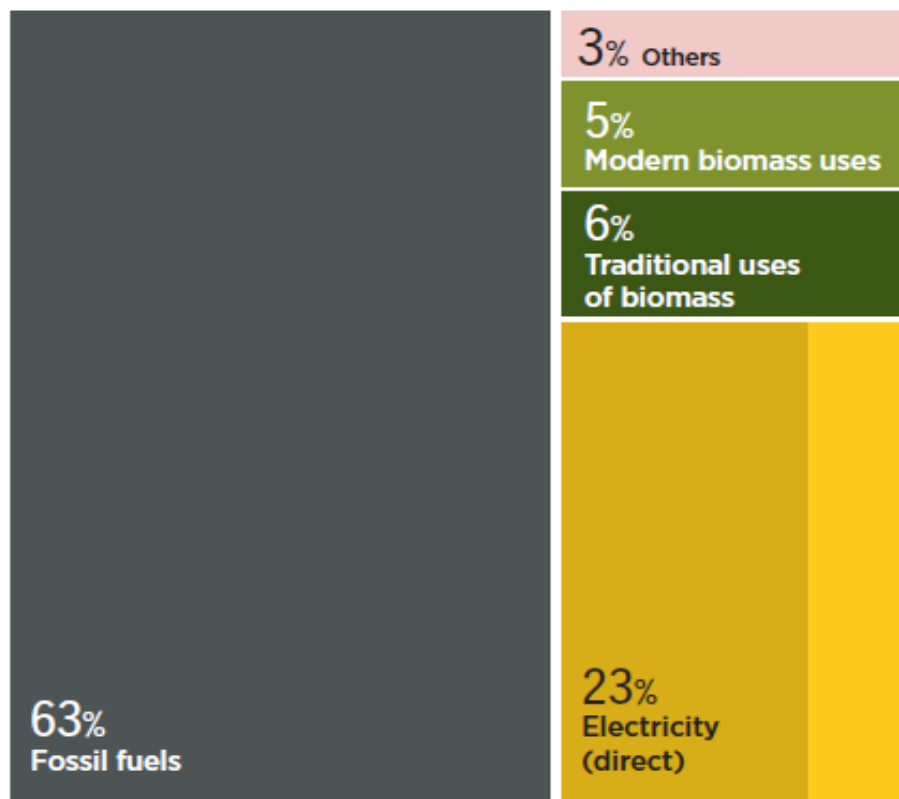
NZE



Total Final Energy Consumption 1,5°C Scenario by IRENA 2024

2022

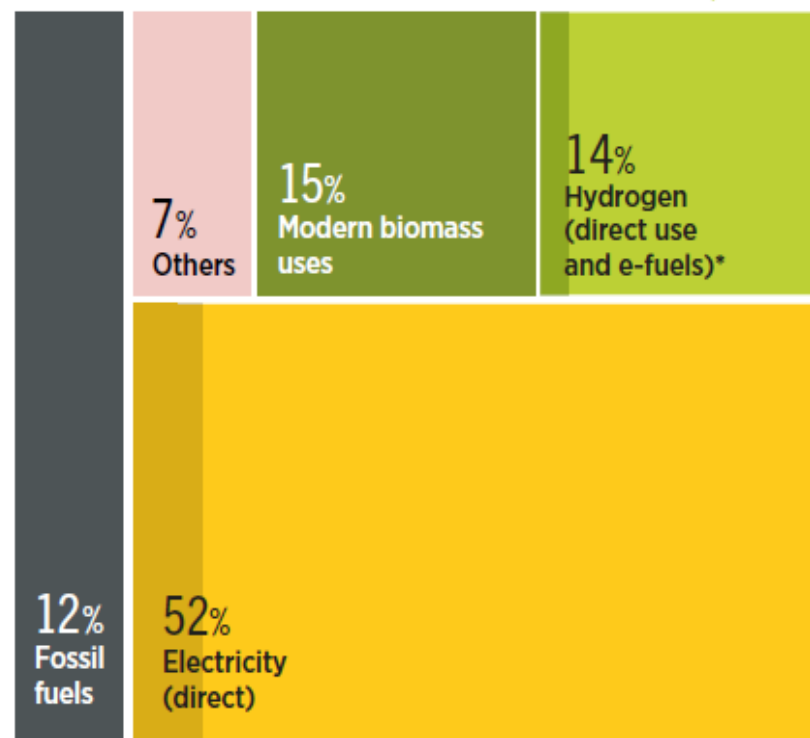
394 EJ Total final energy consumption # 9,4 Gtoe



Renewable share in electricity 29%

1.5°C Scenario: 2050

354 EJ TFE_C # 8,5 Gtoe Renewable share in hydrogen 94%

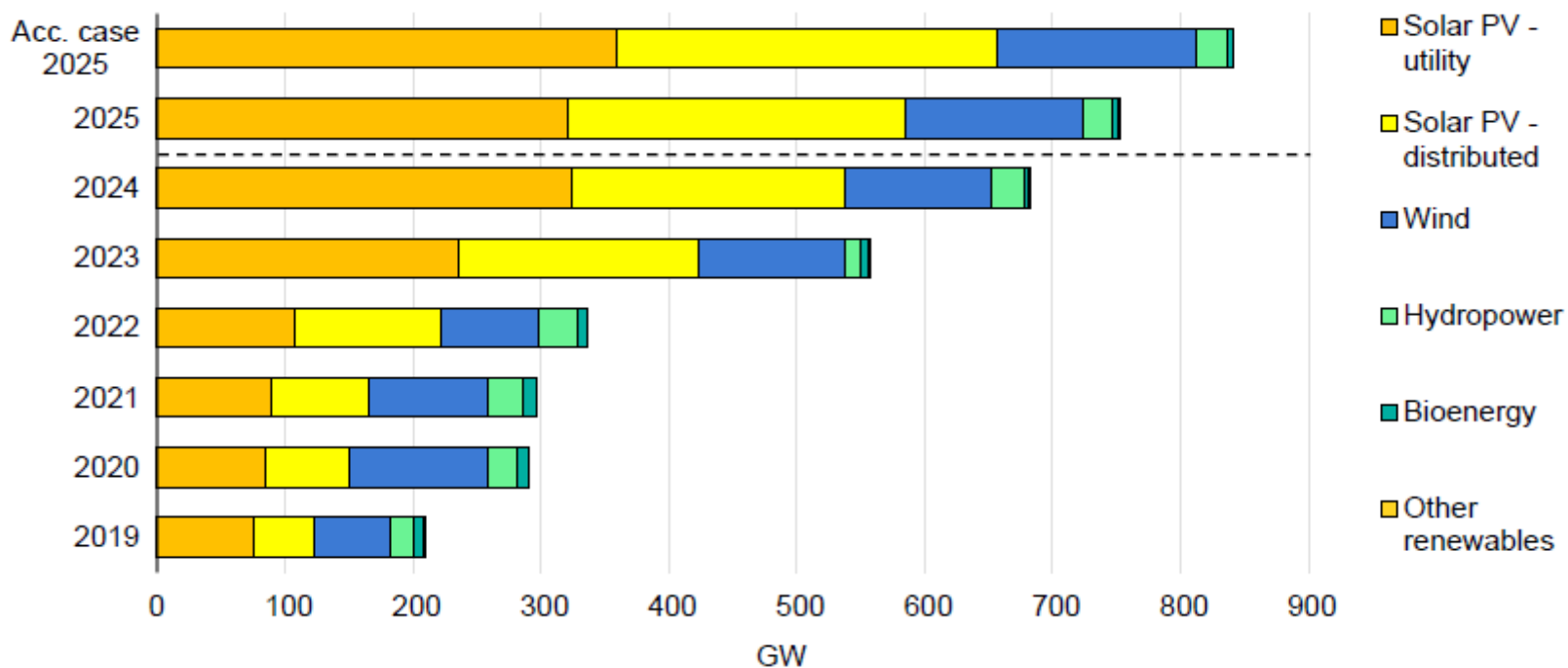


Renewable share in electricity 91%



A huge boost of Renewable Electricity – IEA 2025

Renewable electricity capacity additions by technology, 2019-2025



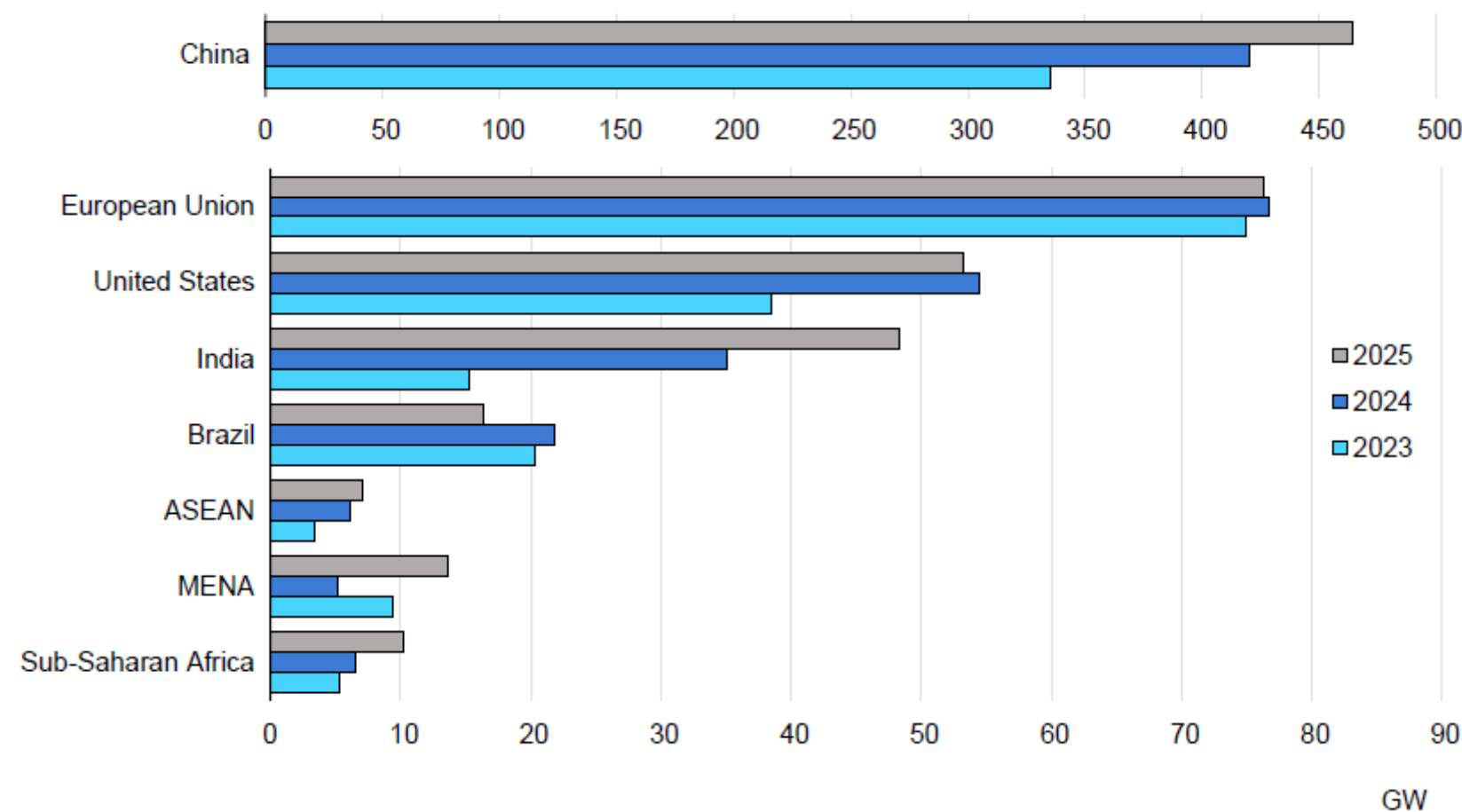
IEA. CC BY 4.0.

Notes: Capacity additions refer to net additions. Historical and forecast solar PV capacity may differ from previous editions of the renewable energy market report. Solar PV data for all countries have been converted to DC (direct current), increasing capacity for countries reporting in AC (alternating current). Conversions are based on an IEA survey of more than 80 countries and interviews with PV industry associations. Solar PV systems work by capturing sunlight using photovoltaic cells and converting it into DC electricity, which is then usually converted using an inverter, as most electrical devices and power systems use AC. Until about 2010, AC and DC capacity in most PV systems were similar, but with developments in PV system sizing, these two values may now differ by up to 40%, especially for utility-scale installations. Solar PV and wind additions include capacity dedicated to hydrogen production.



A huge boost of Renewable Electricity in all Regions – IEA 2025

Renewable electricity capacity additions by country/region, 2023-2024



IEA. CC BY 4.0.

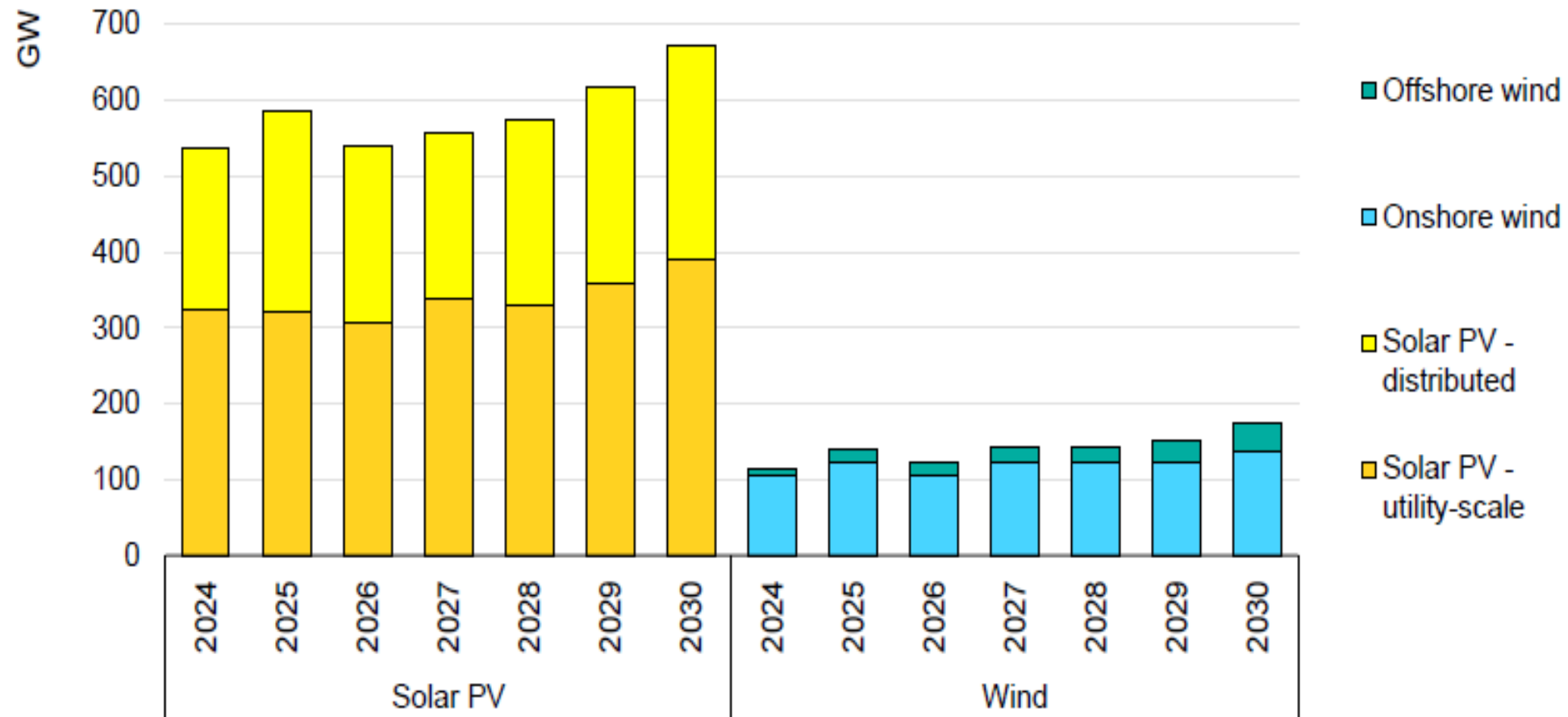
Notes: ASEAN = Association of Southeast Asian Nations. MENA = Middle East and North Africa.

Source: IEA Renewables 2025 – October 2025



A huge boost for Solar and Wind Energy 2024-2030 - IEA 2025

Solar PV and wind capacity additions by segment, main case, 2024-2030

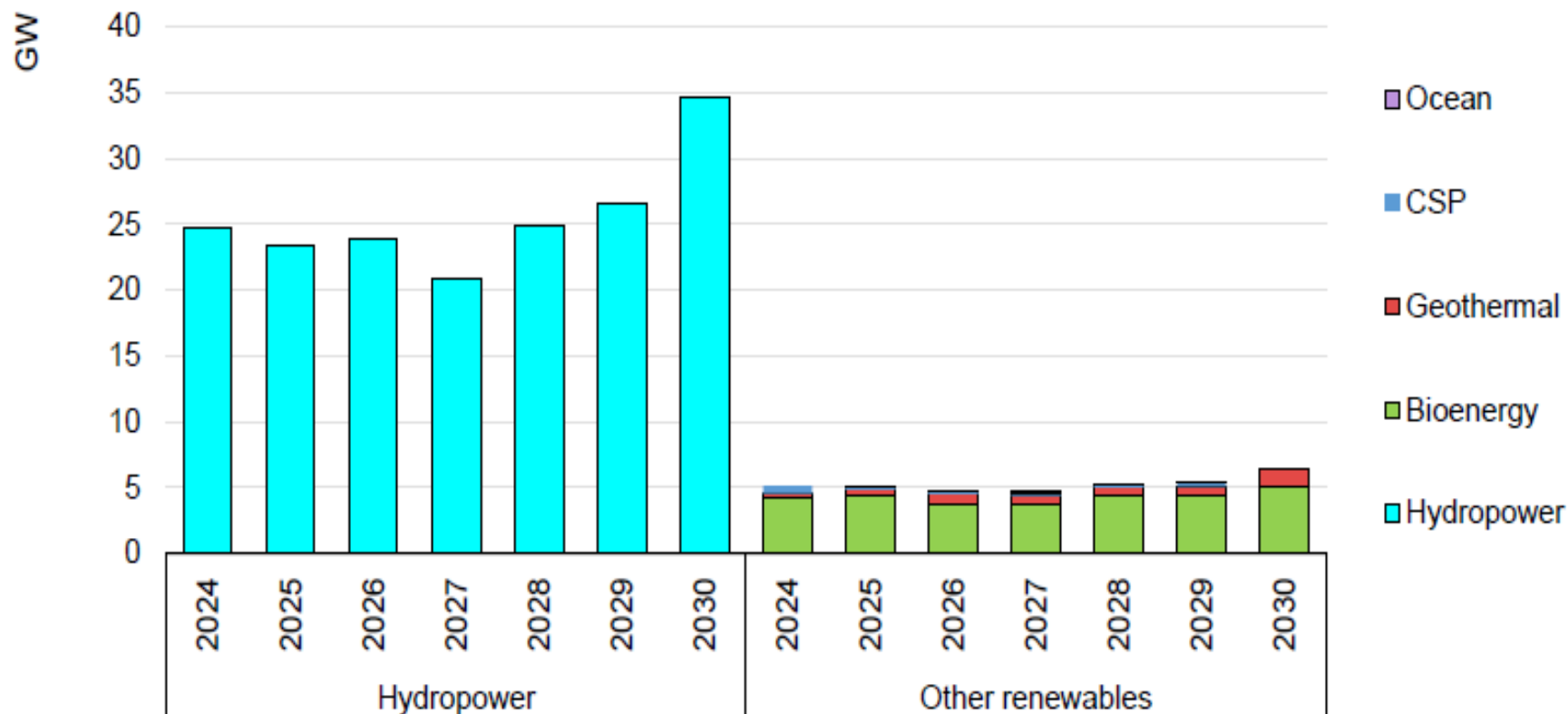


IEA. CC BY 4.0.



To a less extent, Hydropower 2024-2030 - IEA 2025

Hydropower, bioenergy, geothermal, CSP and ocean energy capacity additions, main case, 2024-2030



IEA. CC BY 4.0.

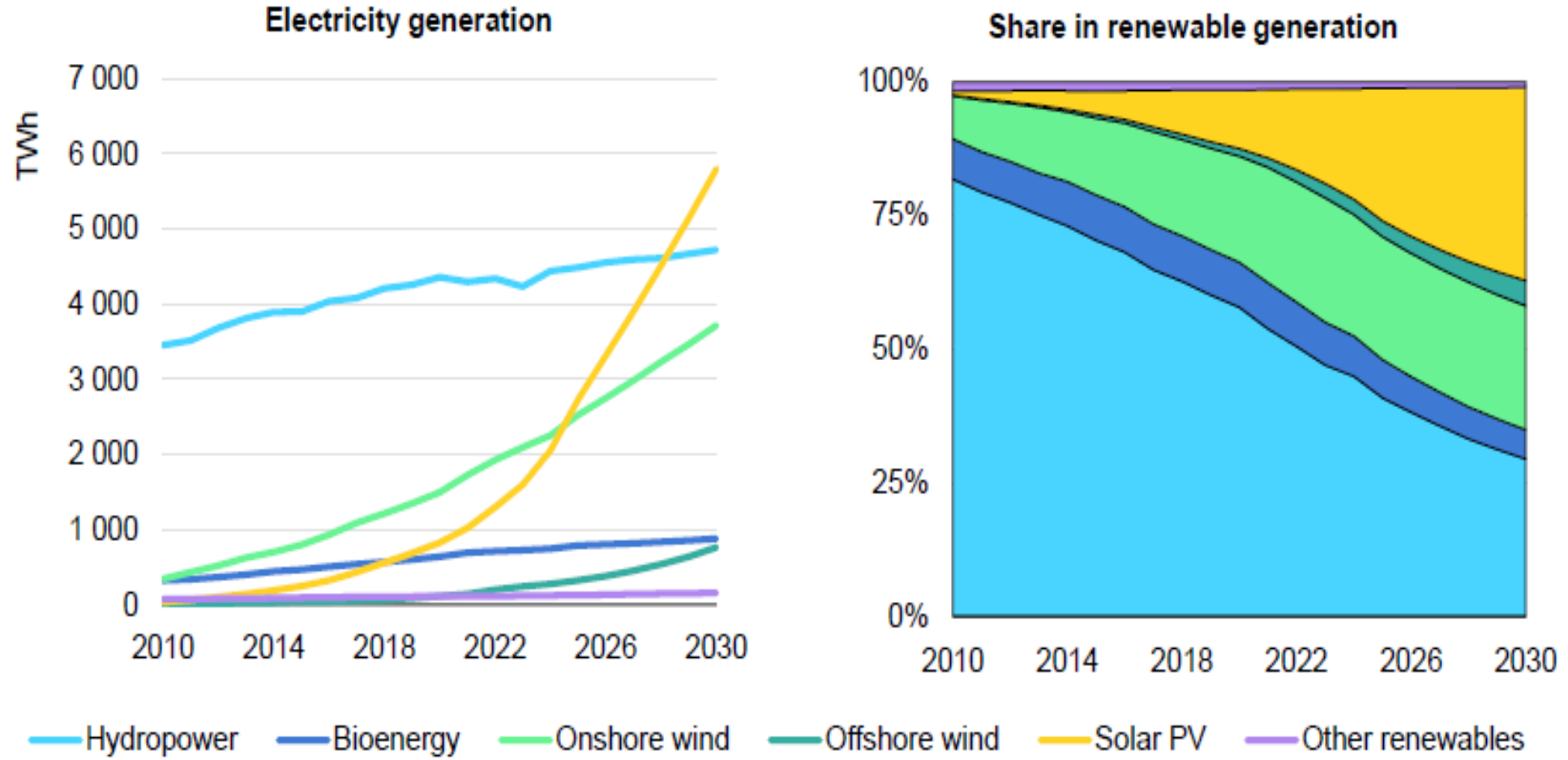
Note: CSP = concentrated solar power.

Source: IEA Renewables 2025 – October 2025



Electricity generation is going to grow extensively thanks to Solar and Wind Energy: Variable Renewable Energy (VRE) 2010-2030 - IEA 2025

Global renewable generation and shares by source, 2010-2030

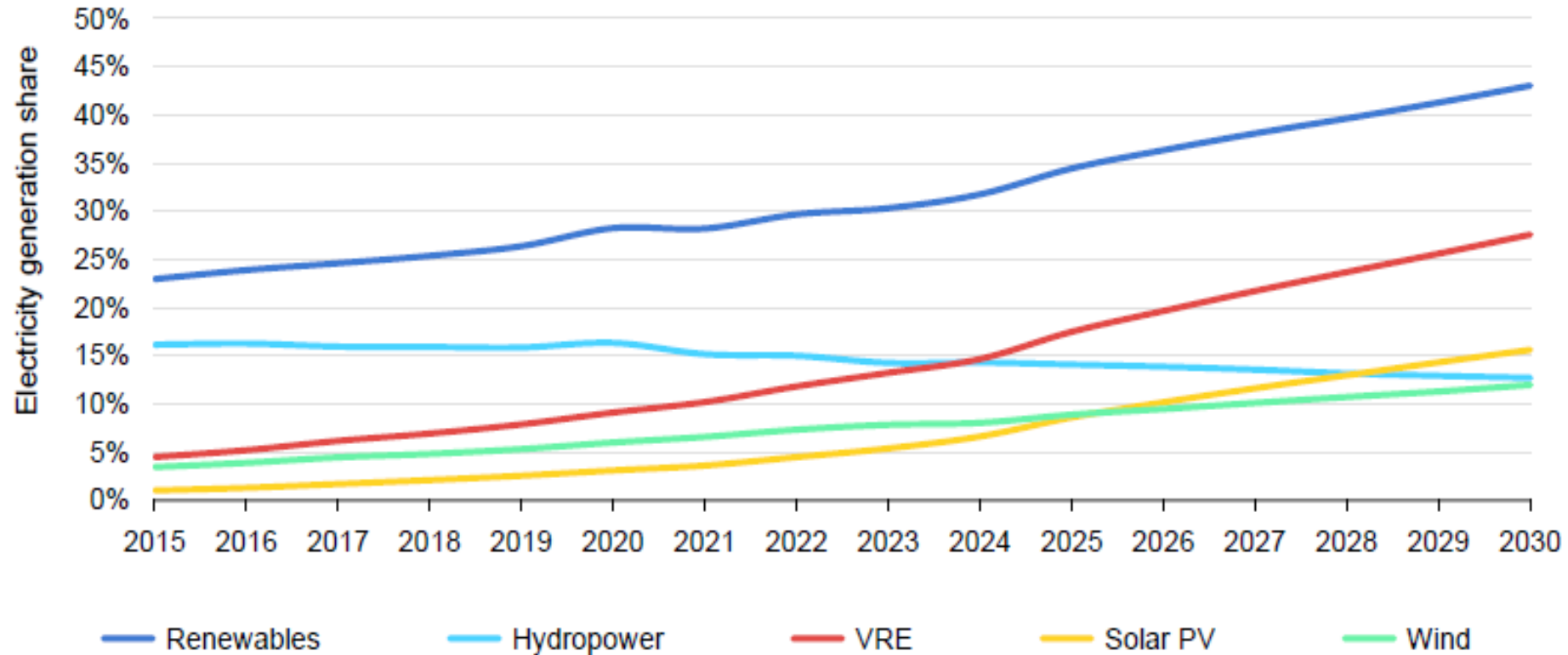


IEA. CC BY 4.0.



Electricity generation is going to grow extensively thanks to Solar and Wind Energy (VRE) 2015-2030 - IEA 2025

Global renewable electricity generation shares by technology, 2015-2030



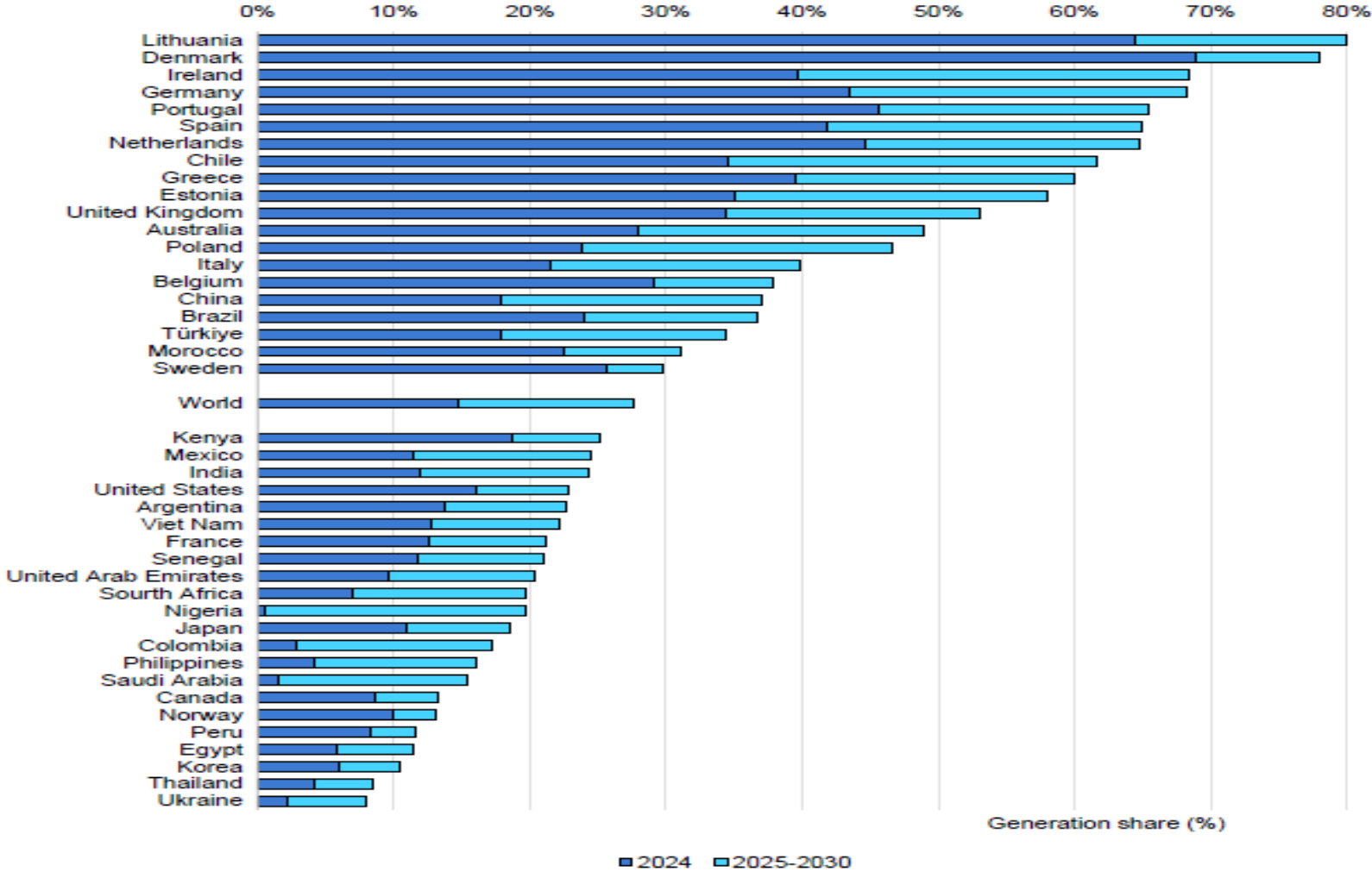
IEA. CC BY 4.0.

Notes: VRE = variable renewable energy. VRE sources include solar PV and wind.



Electricity generation: Northern European countries are the champions for the use of Variable Renewable Energy - IEA 2025

VRE generation shares in 2024 and 2030 for selected countries



Note: VRE = variable renewable energy.

IEA. CC BY 4.0.



Variable Renewable Energy needs fine tuned management to secure stability of Electricity networks - IEA 2025

Curtailment is rising with VRE expansion as countries race to deploy measures to increase flexibility and storage

With rapid solar PV and wind expansion, the curtailment of these resources is becoming more common and visible in several markets. Curtailment occurs when the power system cannot absorb all generated power because of transmission capacity limitations, system stability requirements or supply-demand imbalances. While some curtailment is expected and inevitable, persistent or widespread curtailment often highlights gaps in planning, flexibility or infrastructure. Reducing curtailment thus requires a comprehensive strategy involving transmission, flexibility and co-ordinated system planning.

VRE integration is highly dependent on each country's unique situation, including its grid infrastructure and energy policies. Successful integration relies on the adaptation of strategies to local conditions to overcome challenges and optimise renewable energy use.



1-3

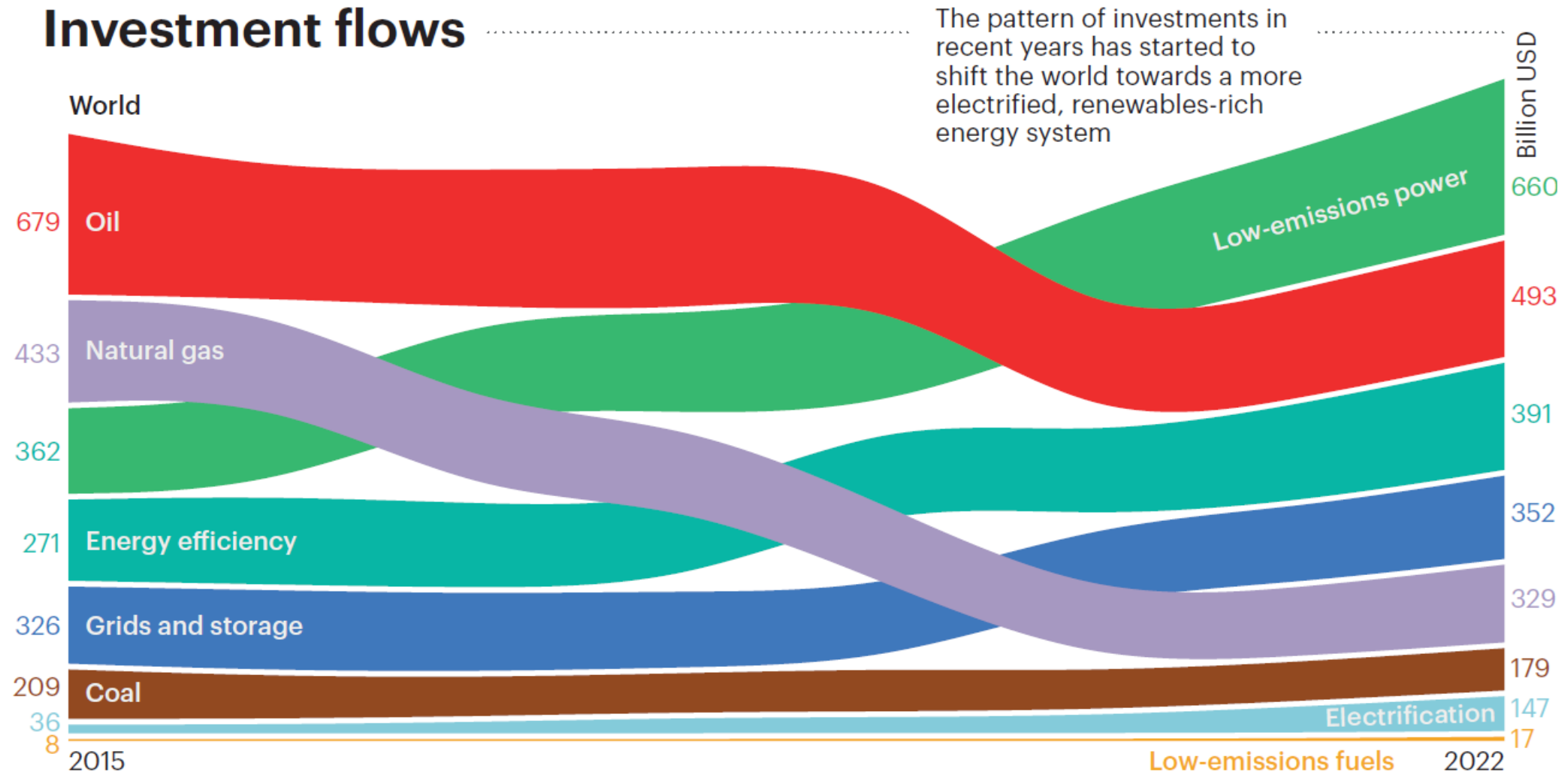
Investments

See BOOK 2 – Chapter 15



Reminder - Energy Investments flows 2015 – 2022 by IEA 2023

A shift from Fossil Fuels to Clean Energy development



Source: IEA WEO 2023



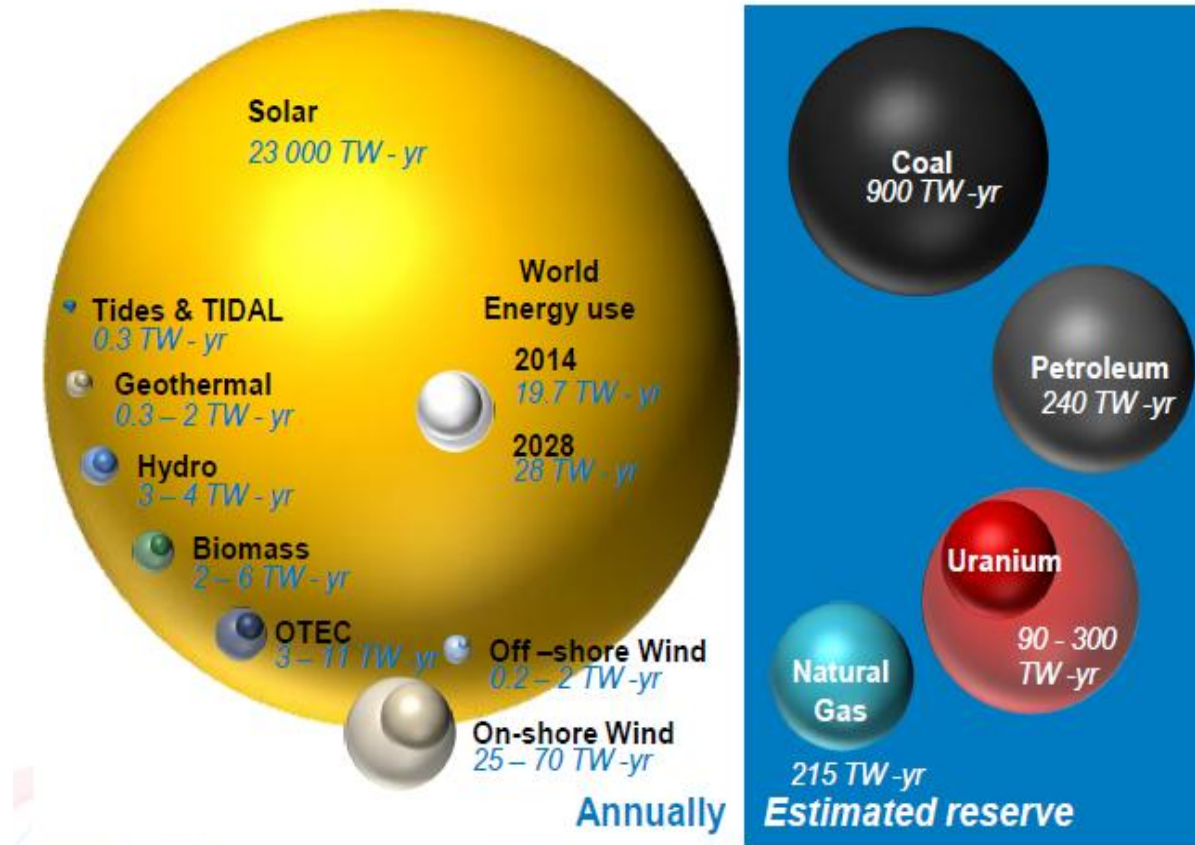
1-4

Potential/Diffusion/ Network



RENEWABLE RESOURCES : WHICH POTENTIAL IN THE WORLD?

PV POTENTIAL



Required surfaces of PV plants to meet the need for energy...

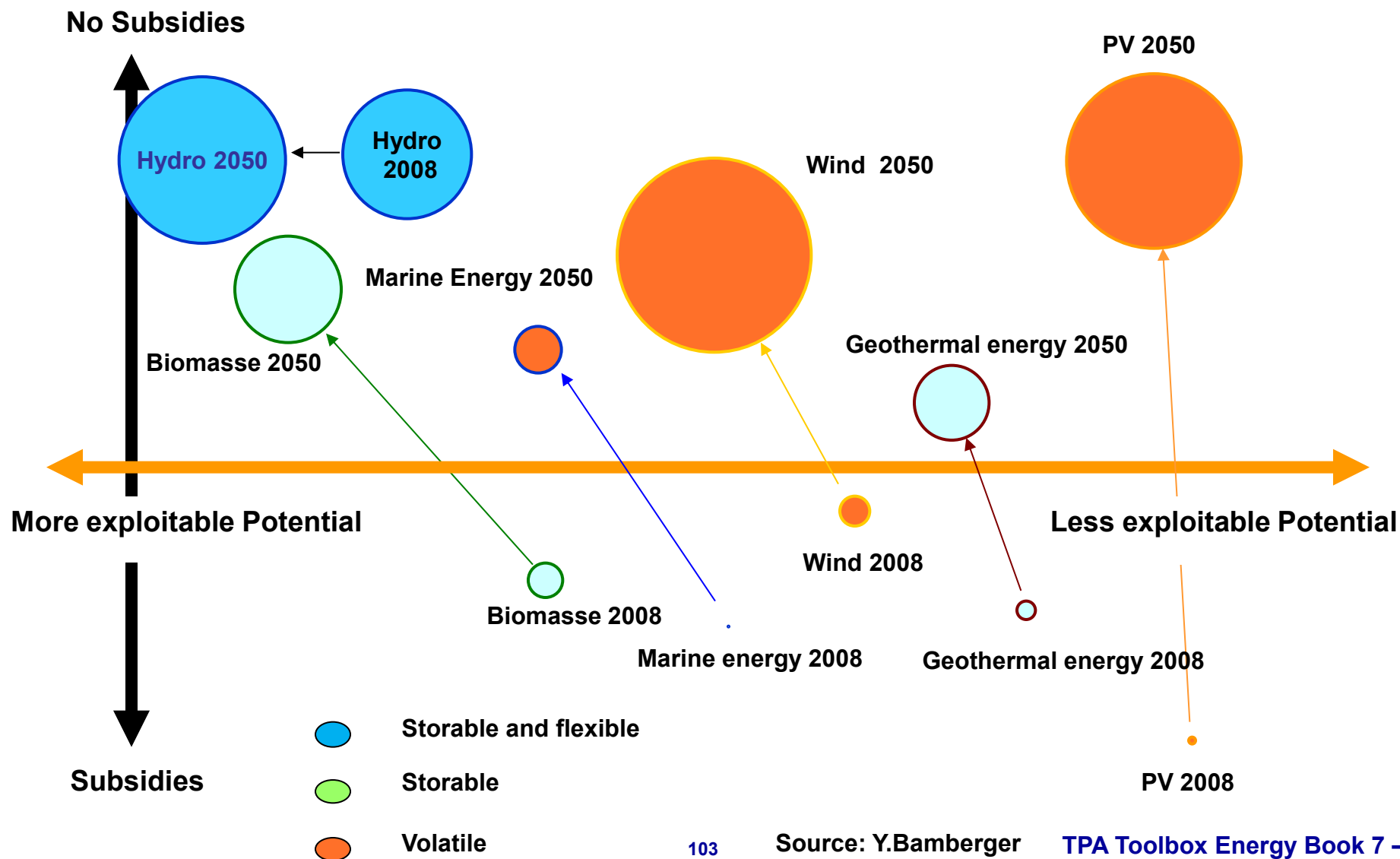


Unlimited energy:

The workable annual sun energy represent
1 000 times
global world electricity use.



RENEWABLE RESOURCES : WHICH POTENTIAL IN THE WORLD AND WHICH COSTS?



A 2016 Vision: RENEWABLE RESOURCES INTEGRATION IN A NEW- BUILT NETWORK

NEW ENERGIES MAP



1-5

Subsidies



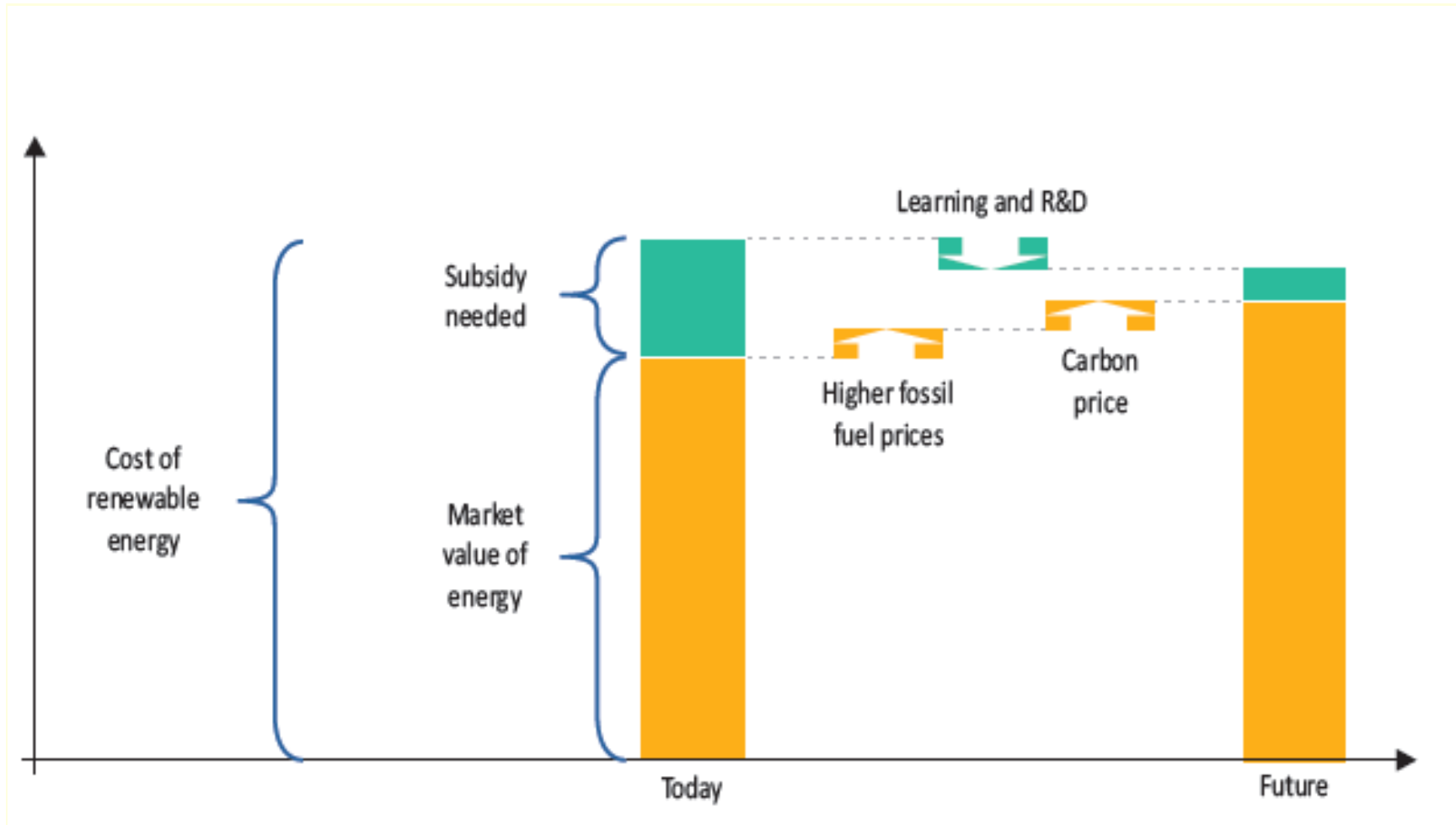
**Today, in certain countries, most of New Renewable
Energies is subsidized.
Any project must be justified in itself on the economic
stand-point
See also Book 2 – Energy, Chapter 16**



**The oil price: an economic marker for energy
to be competitive.
What is a good oil price for the society?
50 - 100 - 130 \$/b?**



The drivers to get renewable energies competitive

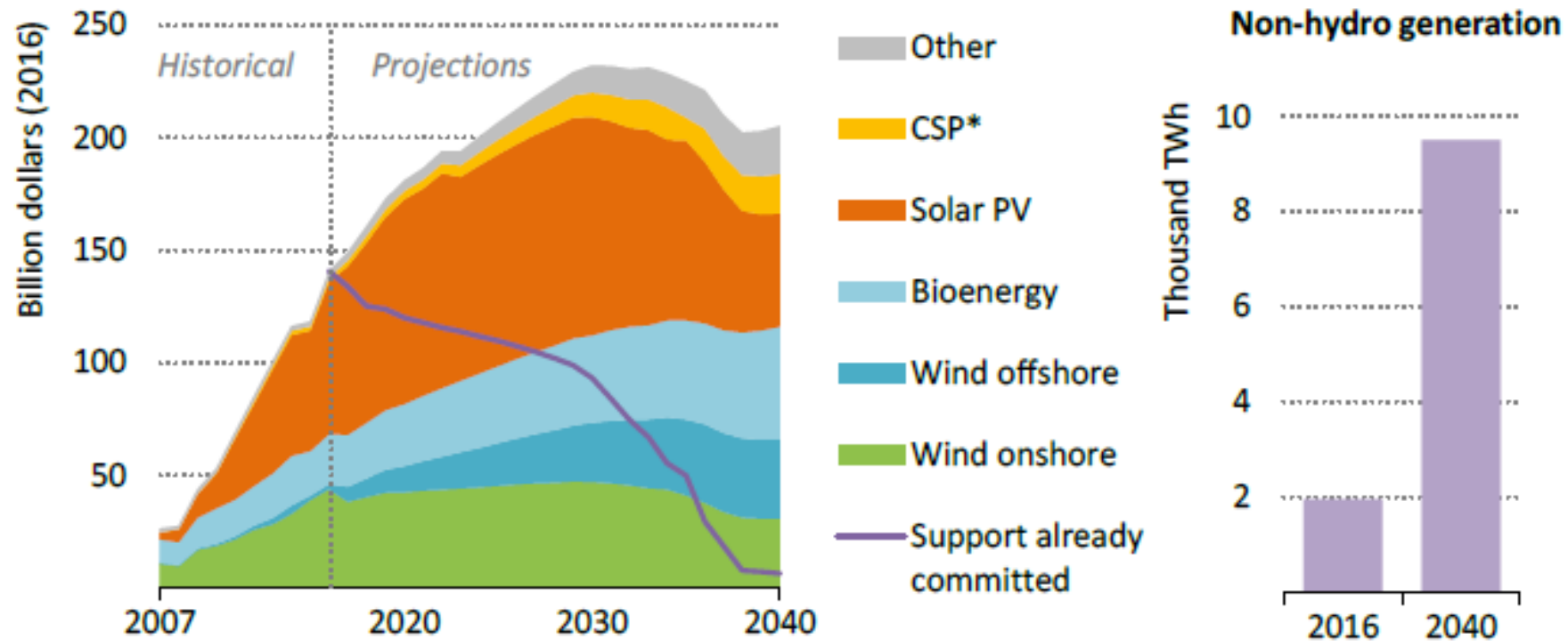


Source: IEA 2011



Renewables Subsidies by Type

IEA 2017 Central Scenario



Global subsidies to renewables increase from \$140 billion today to \$200 billion in 2040, while non-hydro generation more than quadruples

*CSP = concentrating solar power.



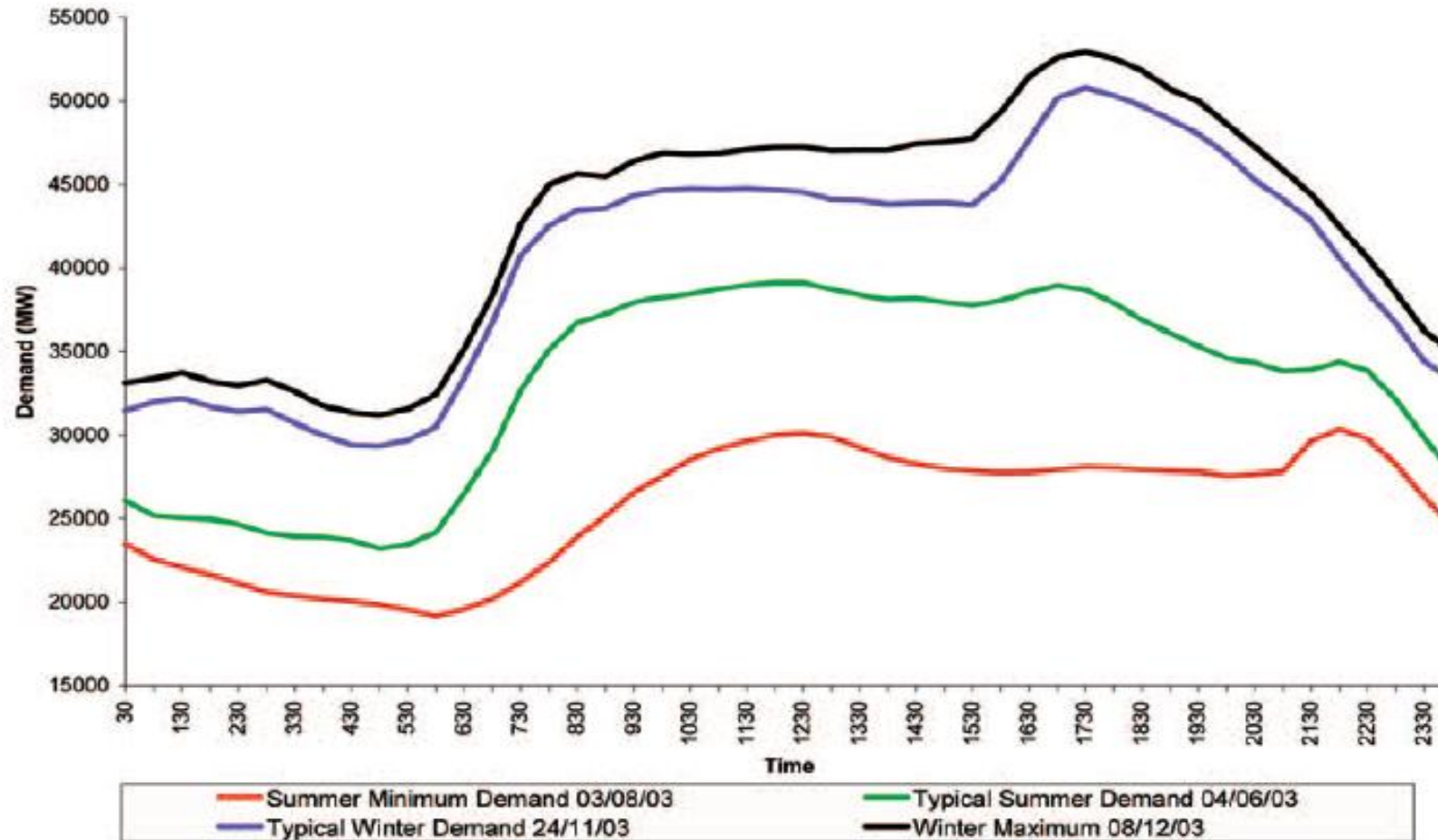
1-6

The question of Intermittency

See also Book 2 Energy – Chapters 10 & 11

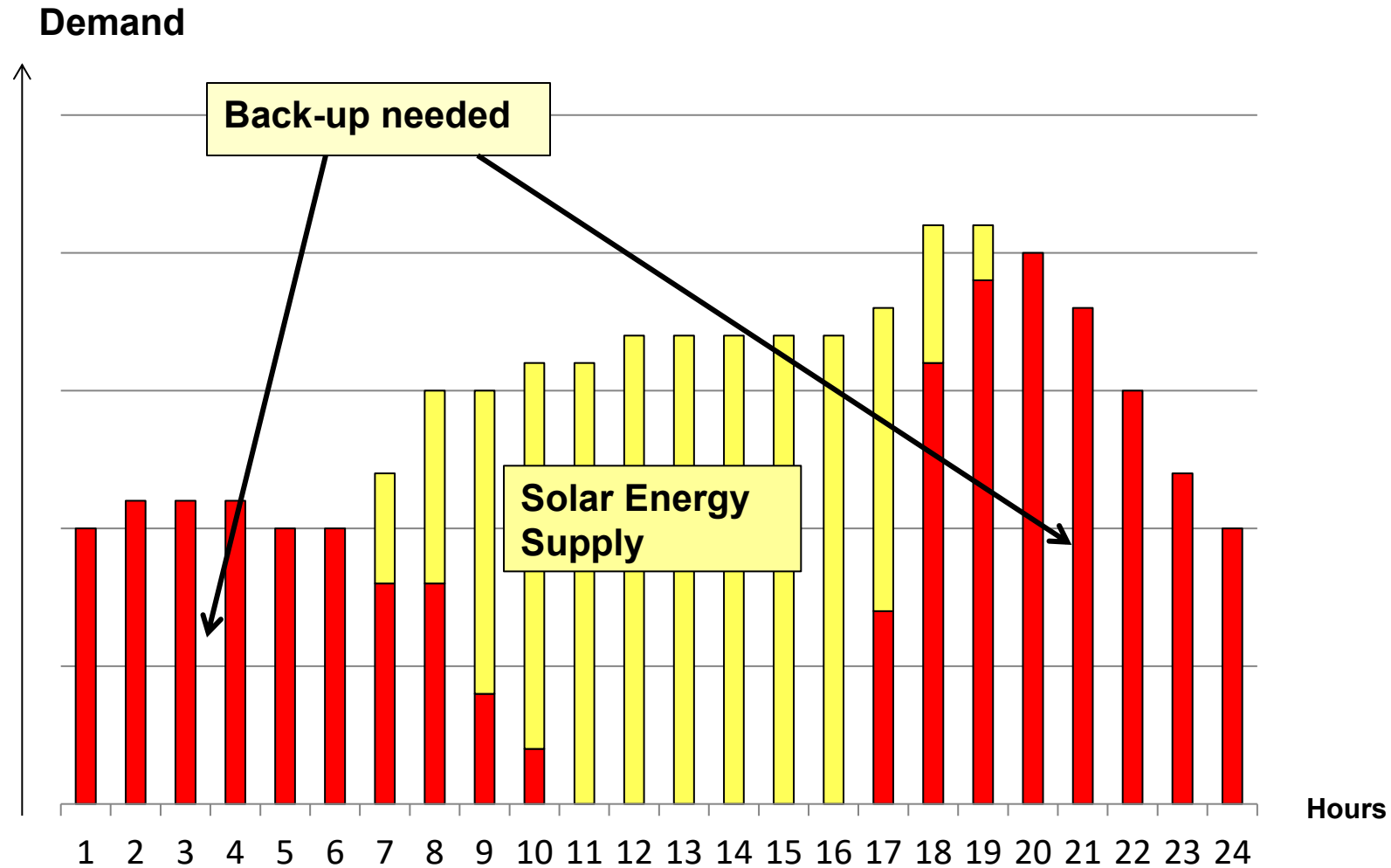


Typical seasonal variations in daily Demand for Electricity in UK



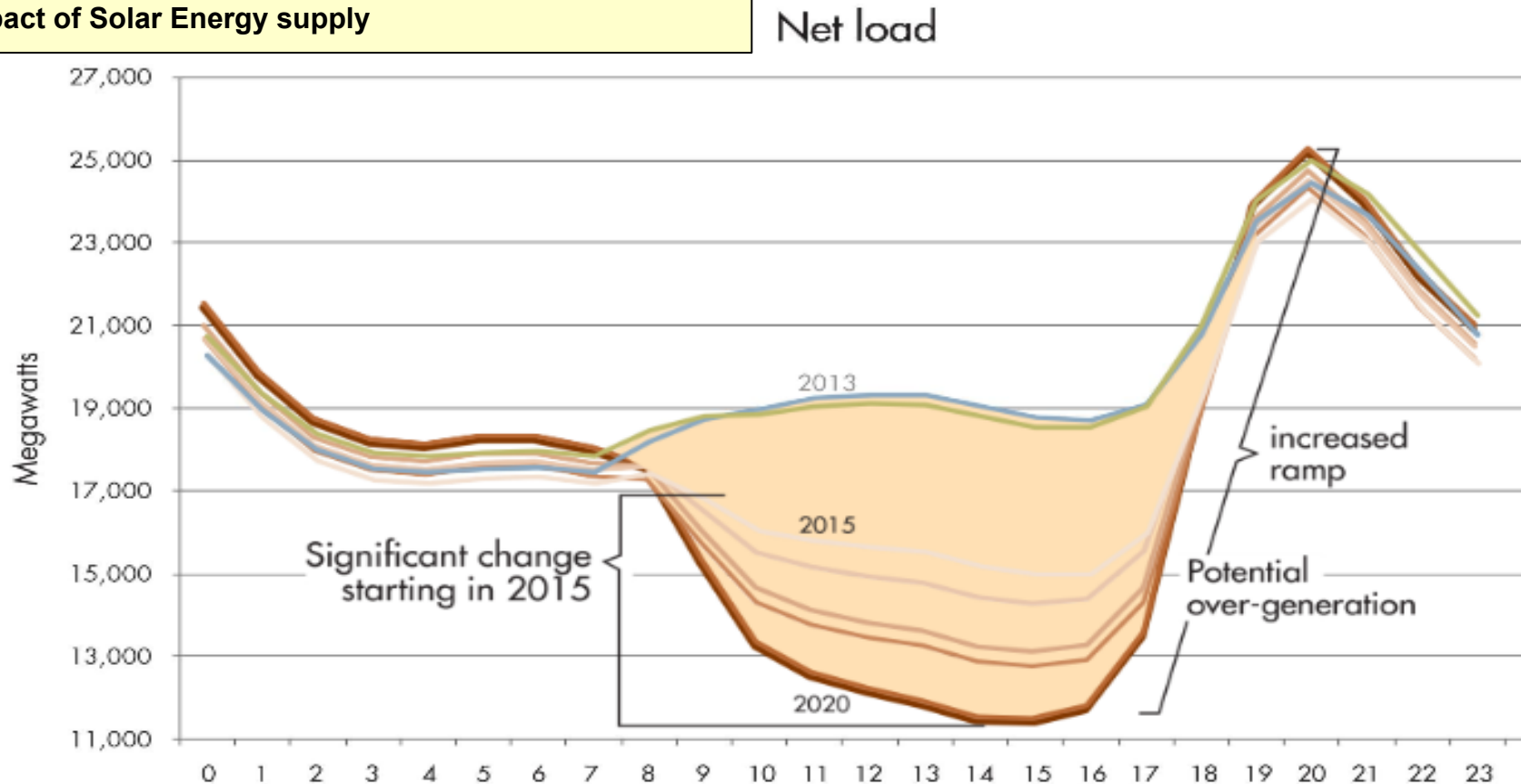
Source: UK Energy Center

Illustration: Typical winter daily Demand for Electricity (Example: Europe)



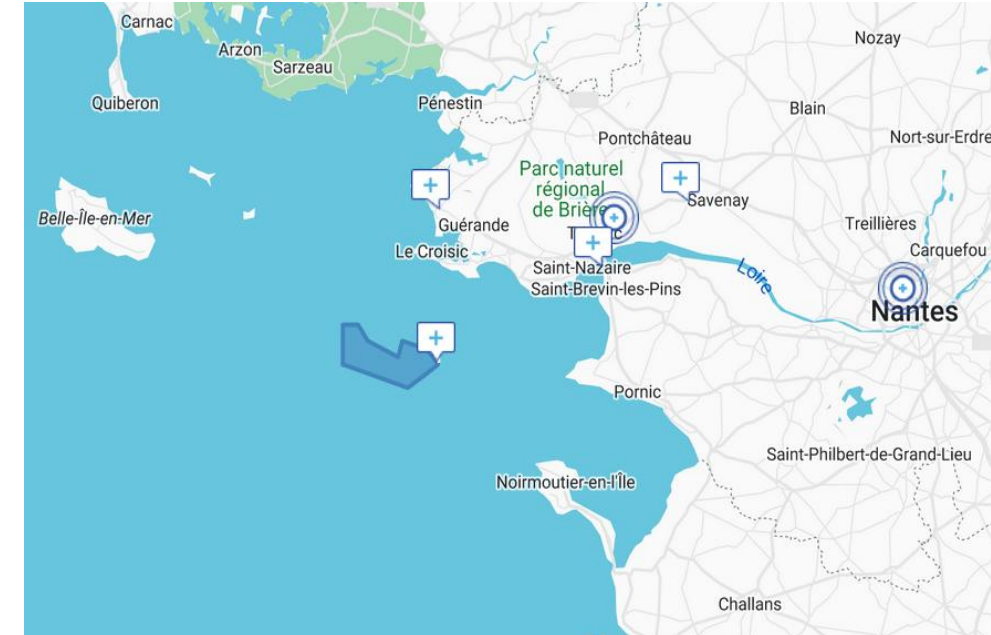
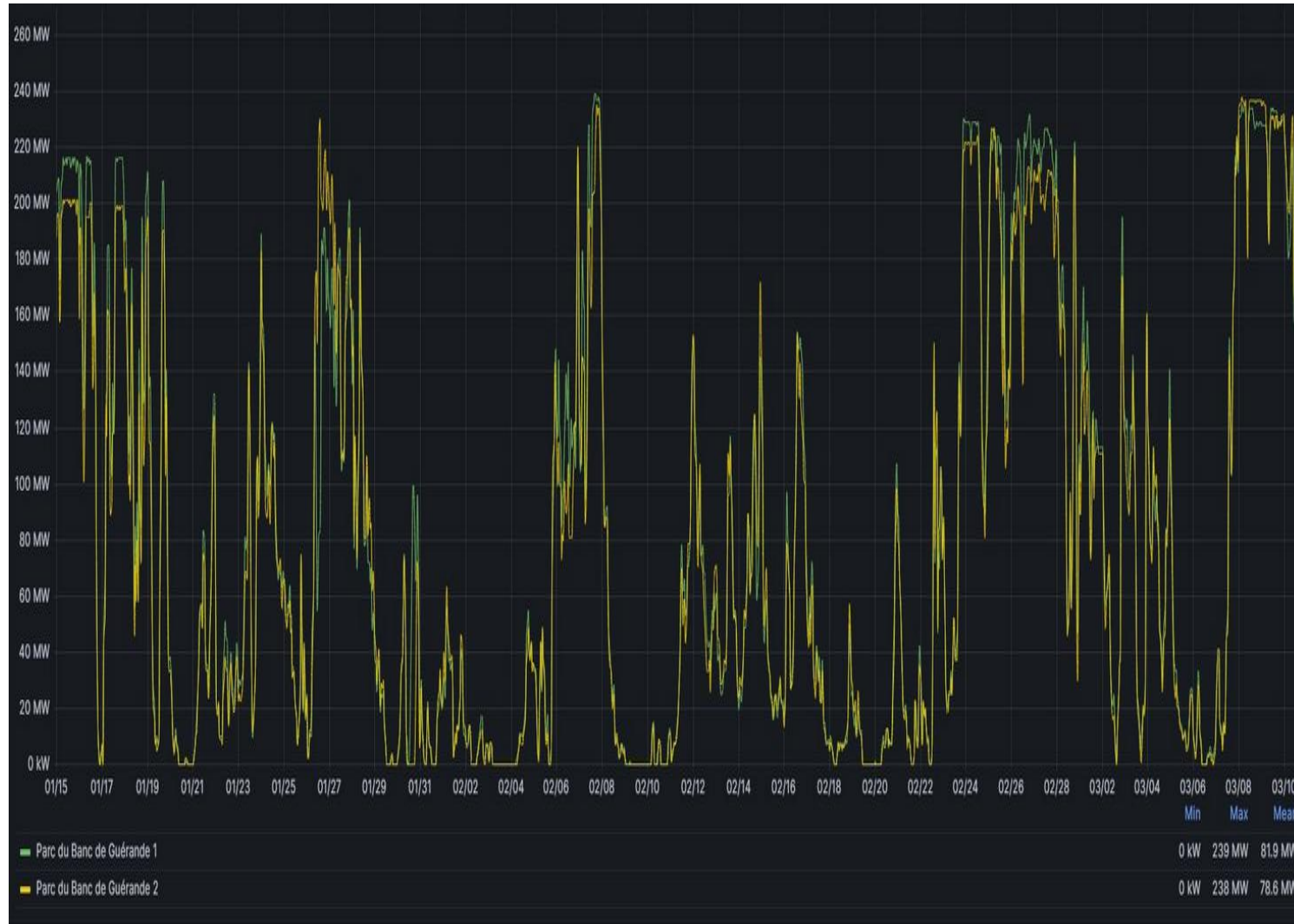
Renewables fluctuations require very rapid ramping of load-following plants (The « Duck Curve »)

Illustration: Daily Net load structure in California
Impact of Solar Energy supply



Example of Intermittency: Saint-Nazaire Wind Farm – France

Electricity Generation from 15 January to 10 March 2023



Wind Farm Saint-Nazaire - France
2 parks: Guérande 1 & Guérande 2
Installed capacity: 2x240 MW = 480 MW
80 turbines, 6 MW each.
Prod. start-up: end November 2022
Prod. January 2023: 180 000 kWh (Source: EDF EN)
(# consumption of 850 000 persons)
Capacity factor # 50%



1-7

Competitiveness



**The competitiveness of Energy Sources
the Leverage Cost Of Electricity (LCOE)
(See BOOK 2 Energy, Chapter 17)**



Levelized cost of Electricity production

Application to various Technologies



From top to down, from left to right:

- Nuclear Power plant, France, Cruas in Ardèche - PWR - 4x900 MW
- Nuclear EPR, France, Flamanville - 1650 MW
- Gas fired CCGT power plant, Bouchain, Northern France – 580 MW
- Heavy Fuel power plant, Liberia - 10 MW
- Coal supercritical power plant, Turkey - 2x600 MW
- Coal IGCC, Japan, Nakoso - 250 MW
- Coal IGCC with CCS, US, Kemper County Mississippi - 580 MW, CO2 for EOR



Levelized cost of Electricity production

Application to various Technologies



From top to down, from left to right:

- Onshore Wind Farm, Germany
- Offshore Wind Farm, France, Saint-Brieuc, Brittany, 500 MW
- Solar PV Utility Scale, UK, West Raynham Norfolk, 50 MWp
- Solar PV Rooftop
- Solar CSP, US
- Hydro Large, Norway, Alta Dam
- Biomass Gaseification, Finland, Vaasa, 140 MW
- Geothermal, Iceland, Svartsengi, 75M W_e + 150 MW_{th}



**LCOE is very dependant upon changes of the environment (prices of fuels, cost of new nuclear and production costs of solar energy in particular)
For wind energy and solar energy, cost of intermittency has to be added**



1-8

A Zoom on France

History of Energy Plans PPE's

See also Book 2 –Energy - Chapter 5



France – Programmation Pluriannuelle de l'Énergie (PPE) Published in February 2026



Stratégie française
pour l'énergie
et le climat

Dossier de presse
Février 2026



France – History of Laws on Energy Transition & PPE



France – Law on Energy Transition

17 August 2015

Objectives:

- Reduce by 40% GHG emissions in 2030 vs 1990.
- Divide by 4 the GHG emissions in 2050 vs 1990.
- Reduce by 50% the Energy consumption in 2050 vs 2012 reference.
- Reduce Fossil fuels by 30% in 2030 vs 2012 reference.
- Get 23% of Renewables in the Energy Mix in 2020 and 32% in 2030.
- Diversify the Energy Mix for Electricity Generation: 50% Nuclear (vs 75% today), 40% Renewable in 2030.
- Increase of « Contribution Energie Climat », ex. Carbon Tax from 14,5 €/tCO₂ today to 56 €/t in 2020, then 100 €/t in 2050.

Achievable objectives?



France
Programmation Pluriannuelle de l'Energie (PPE)
published in January 2019, adopted in April 2020



Programmation Pluriannuelle de l'Energie (PPE) published in January 2019, adopted in April 2020

Les Programmes pluriannuels de l'énergie (PPE), outils de pilotage de la politique énergétique, ont été créés par la loi relative à la transition énergétique pour la croissance verte. Elles concernent la métropole continentale et les zones dites non interconnectées (ZNI), à savoir la Corse, la Réunion, la Guyane, la Martinique, la Guadeloupe, Wallis et Futuna et Saint-Pierre et Miquelon. La PPE de métropole continentale est élaborée par le Gouvernement tandis que les PPE des ZNI sont co-élaborées avec les collectivités territoriales.



SYNTHÈSE



**STRATÉGIE FRANÇAISE POUR
L'ÉNERGIE ET LE CLIMAT**
**PROGRAMMATION
PLURIANNUELLE DE L'ÉNERGIE**

2019-2023

2024-2028



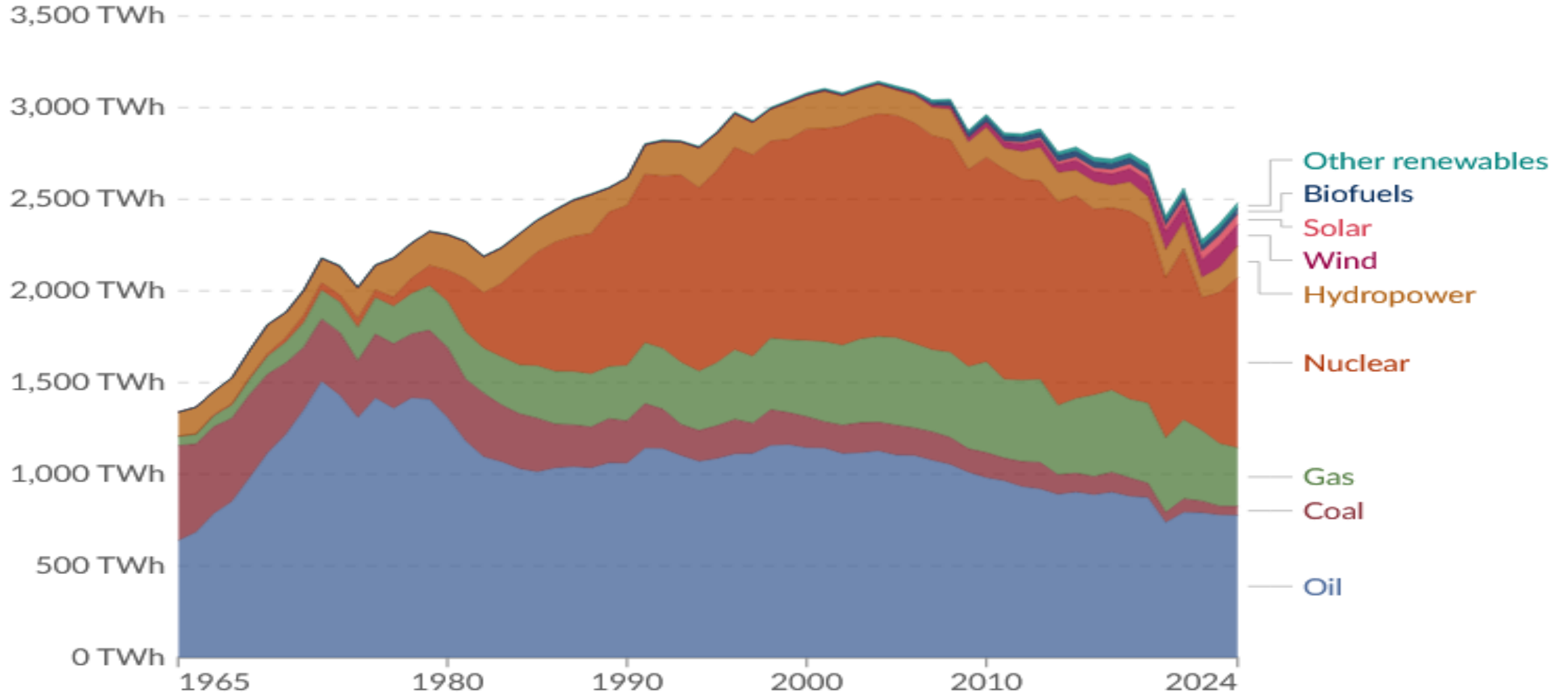
France PPE 2020: Some figures

Consommation finale d'énergie	Baisse de 7,6 % en 2023 et de 16,5 % en 2028 par rapport à 2012 <i>Soit une réduction de 6,3 % en 2023 et de 15,4 % en 2028 par rapport à 2018</i>
Consommation primaire des énergies fossiles	Baisse de 20 % de la consommation primaire d'énergies fossiles en 2023 et de 35 % en 2028 par rapport à 2012
Émissions de gaz à effet de serre issues de la combustion d'énergie	277 MtCO ₂ en 2023 227 MtCO ₂ en 2028 <i>Soit une réduction de 14 % en 2023 et de 30 % en 2028 par rapport à <u>2016</u> (322 MtCO₂) Soit une réduction de 27 % en 2023 et 40 % en 2028 par rapport à <u>1990</u>.</i>
Consommation de chaleur renouvelable	Consommation de 196 TWh en 2023 Entre 218 et 247 TWh en 2028 Soit une augmentation de 25 % en 2023 et entre 40 et 60 % en 2028 de la consommation de chaleur renouvelable de 2017 (154 TWh)
Production de gaz renouvelables	Production de biogaz à hauteur de 24 à 32 TWh en 2028 sous l'hypothèse d'une baisse des coûts (4 à 6 fois la production de 2017)
Capacités de production d'électricité renouvelables installées	73,5 GW en 2023, soit + 50 % par rapport à 2017 101 à 113 GW en 2028, doublement par rapport à 2017
Capacités de production d'électricité nucléaire	4 à 6 réacteurs nucléaires fermés d'ici 2028 dont ceux de Fessenheim. Fermeture de 14 réacteurs nucléaires d'ici 2035, date d'atteinte d'une part de 50 % d'électricité nucléaire dans le mix électrique.
Croissance économique	Hausse de 1,3 point de PIB en 2023 par rapport au scénario tendanciel, et de 2,1 point en 2028
Emplois	Création d'environ 238 000 emplois en 2023 par rapport au scénario tendanciel et de 440 000 emplois en 2028
Revenu disponible brut des ménages	Hausse du pouvoir d'achat des ménages de 1 point en 2023, par rapport au scénario tendanciel et de 2,2 points en 2028

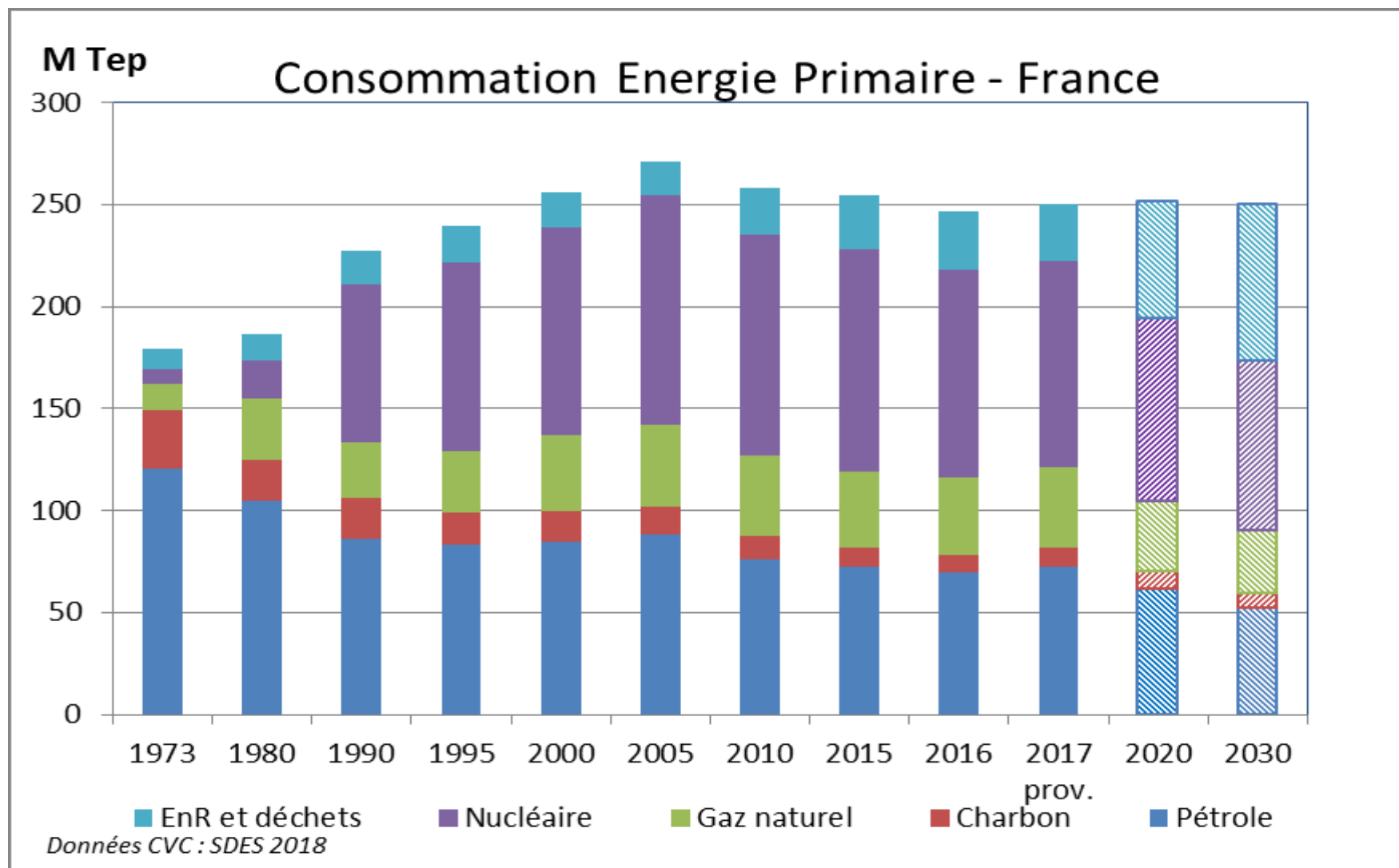


France: Evolution of Primary Energy Consumption by EI (TWh)

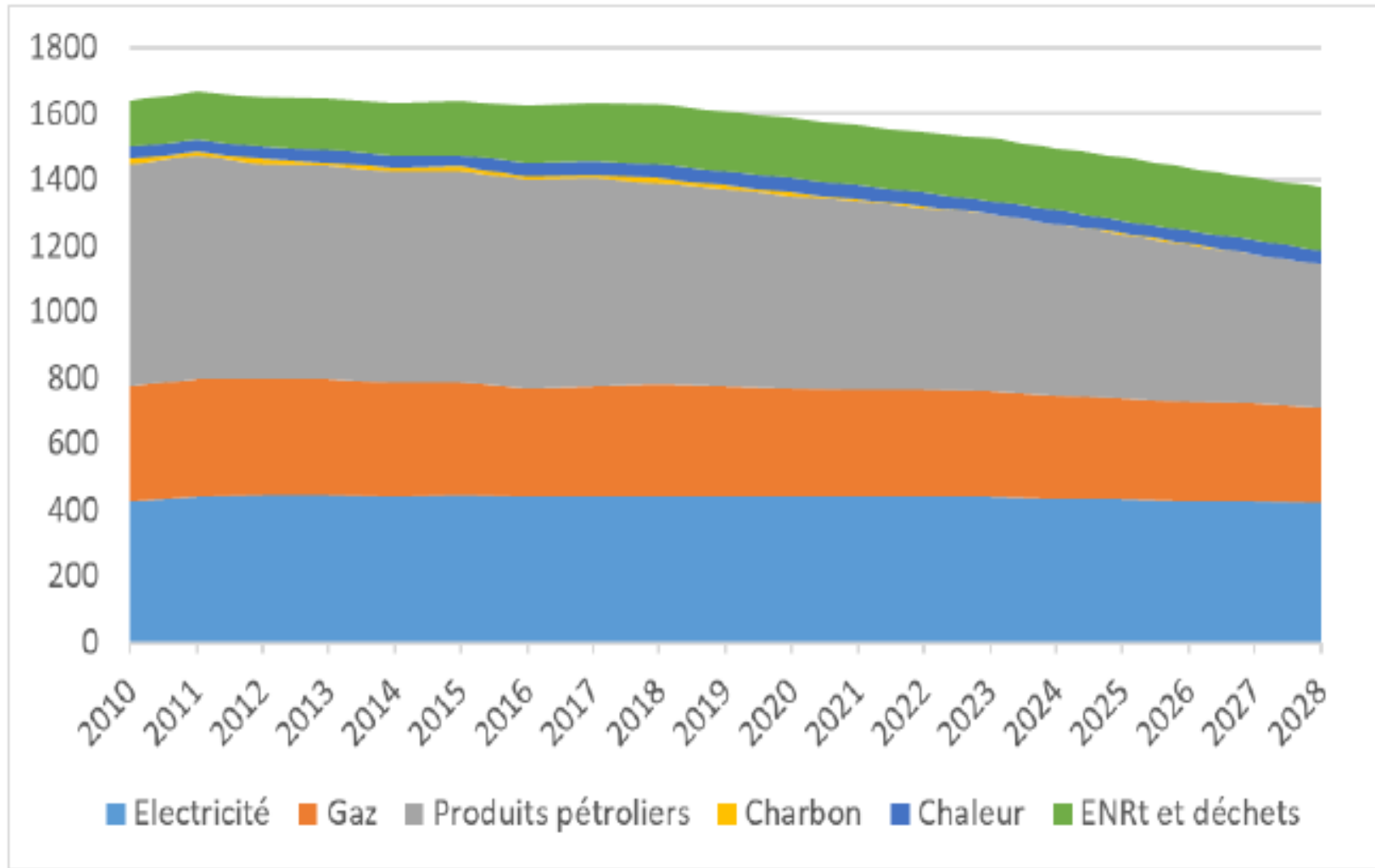
1,4% of World Primary Energy Consumption in 2024



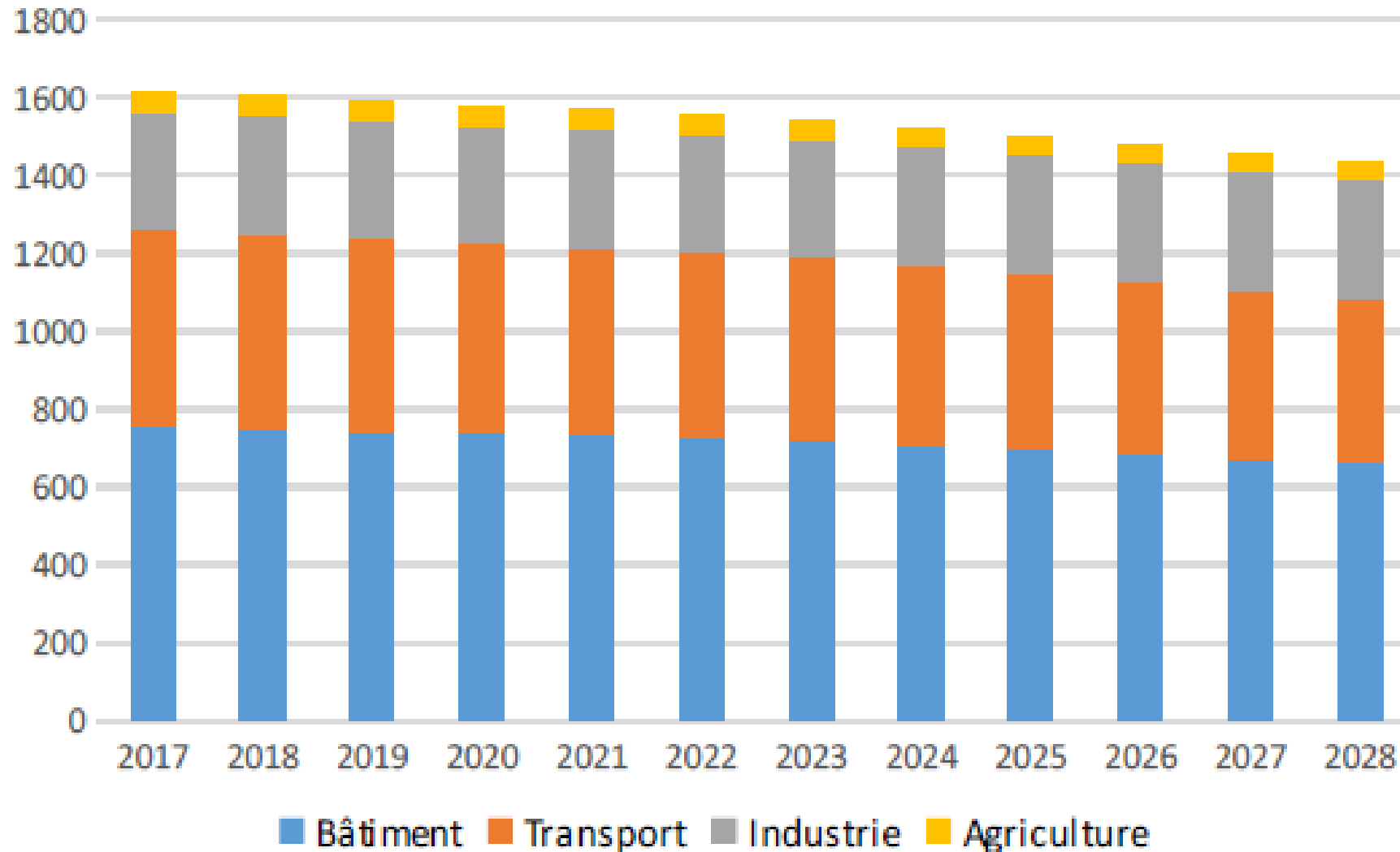
PPE 2020: Evolution of Primary Energy Consumption (Mtep)



PPE 2020: Evolution of Final Energy Consumption by vectors (TWh)



PPE 2020: Evolution of Final Energy Consumption by sectors (TWh)



France – Situation of Renewable Energy for Electricity Production - Situation 2013 & PPE 2020

Technologies	Instal. Power End 2013 (GW)	Production 2013 (TWh)	Instal. Power End 2017 (GW)	Instal. Power End 2023 (GW)	Instal. Power End 2028 (GW)
Hydro	25,7	75,7	25,7	25,7	26,4 – 26,7
PV	5,4	5,1	8,0	20,6	35,6 – 44,5
Wind onshore	8,8	16,0	13,8	24,6	34,1 – 35,6
Wind offshore + Marine Energy	0,0	0,4	0,2	2,4 (Floating: 0,1)	4,7 – 5,2
Biomass	0,0	2,4	0,8	0,8	0,8
Biogas	0,0	1,5	0,1	0,3	0,3 – 0,4
Urban Waste	0,0	2,2	0,0	0,0	0,0
Total	40,8	103,2	48,6	74,0	102 – 113



PPE 2020 - A zoom on Wind Offshore

Ceiling Prices for future Call for Tenders Prices are declining

Date <u>d'attribution</u> de l'AO	2019	2020	2021	2022	2023	>2024
Eolien flottant			250 MW <i>Bretagne Sud</i> (120 €/MWh)	2 x 250 MW <i>Méditerranée</i> (110 €/MWh)		1 000 MW par an, posé et/ou flottant, selon les prix et le gisement, avec des tarifs cibles convergeant vers les prix de marché sur le posé
Eolien posé	600 MW <i>Dunkerque</i> (45 €/MWh)	1 000 MW <i>Manche Est</i> <i>Mer du Nord</i> (60 €/MWh)*	500 – 1 000 MW <i>Sud-Atlantique**</i> (60 €/MWh)		1 000 MW (50 €/MWh)	

* Pour ce projet, la date de 2020 est la date de lancement de la procédure de mise en concurrence.

** Dans ce cadre, un projet éolien en mer au large d'Oléron pourrait être attribué.

Les dates indiquées sont les dates auxquelles un lauréat sera sélectionné, en fin de procédure de dialogue concurrentiel ; les prix indiqués sont les prix cibles des appels d'offres sur la base desquels seront fixés les prix plafonds des appels d'offres. Les projets attribués à partir de 2024 portent notamment sur des extensions des parcs éoliens en mer précédents, avec un raccordement mutualisé.



France
Rapport ADEME
Coûts des Energies Renouvelables et de
Récupération 2012 - 2022
Edition 2024

www.ademe.fr/couts-energies-renouvelables-recuperation-france



Warning!!
Levelized Cost of Electricity (LCOE) is very
dependant upon the Discount Rate Value
ADEME uses Discount Rate = 4%/5%

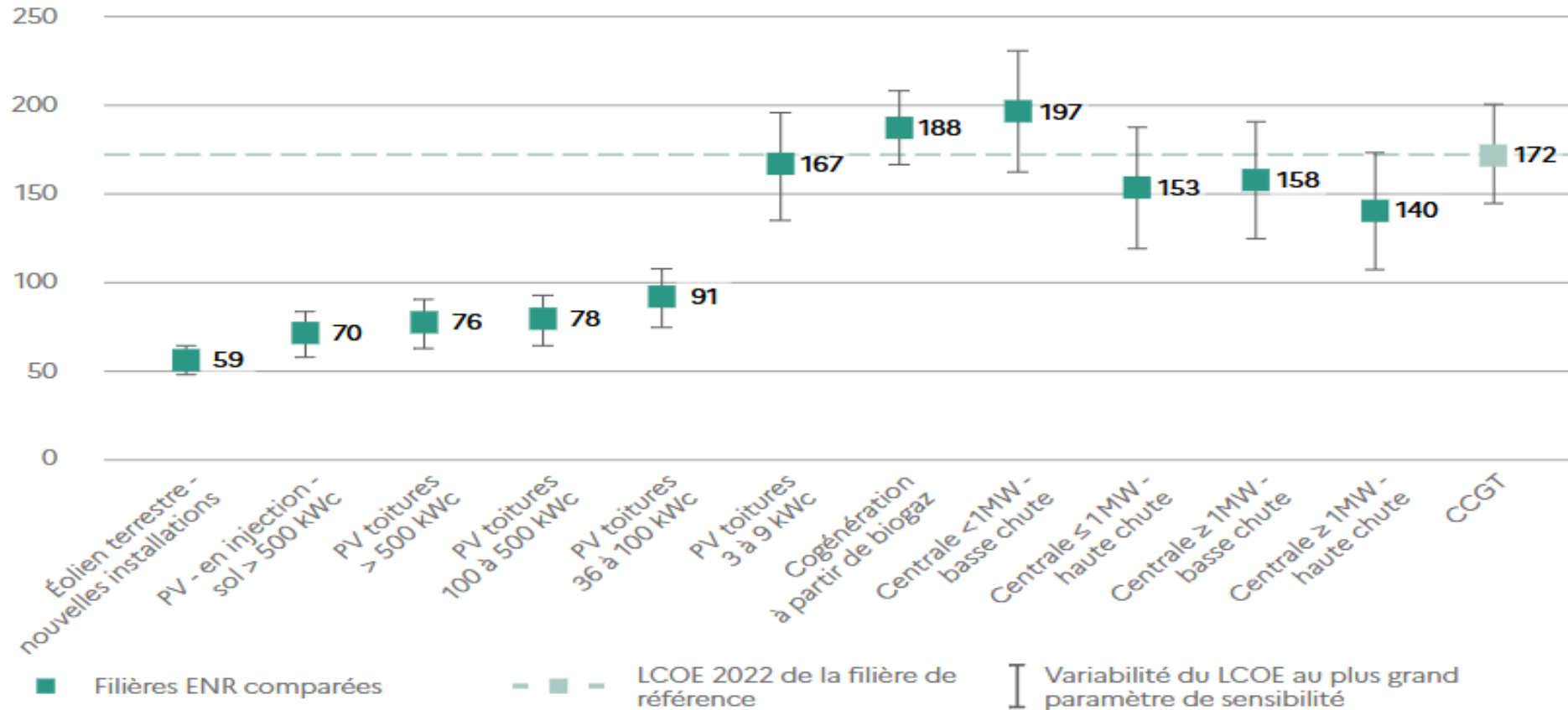


Discount Rate used by ADEME between 4 and 5%

Filière/technologie		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
ÉLECTRICITÉ												
Éolien terrestre	TA	7%	6%	6%	6%	5%	5%	5%	4%	4%	4%	4%
	dont risque	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Photovoltaïque centrales au sol	TA	6%	6%	6%	6%	5%	5%	5%	4%	4%	4%	4%
	dont risque	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Photovoltaïque sur grandes toitures	TA	6%	6%	6%	6%	6%	6%	5%	5%	5%	5%	5%
	dont risque	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Photovoltaïque petites et moyennes toitures	TA	6%	6%	6%	6%	6%	6%	5%	5%	5%	5%	5%
	dont risque	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Hydraulique	TA					6%	6%	5%	5%	5%	5%	5%
	dont risque					1%	1%	1%	1%	1%	1%	1%
CCGT Gaz	TA	6%	6%	6%	6%	5%	5%	5%	4%	4%	4%	4%
	dont risque	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%



France - LCOE of various Technologies - Year 2022



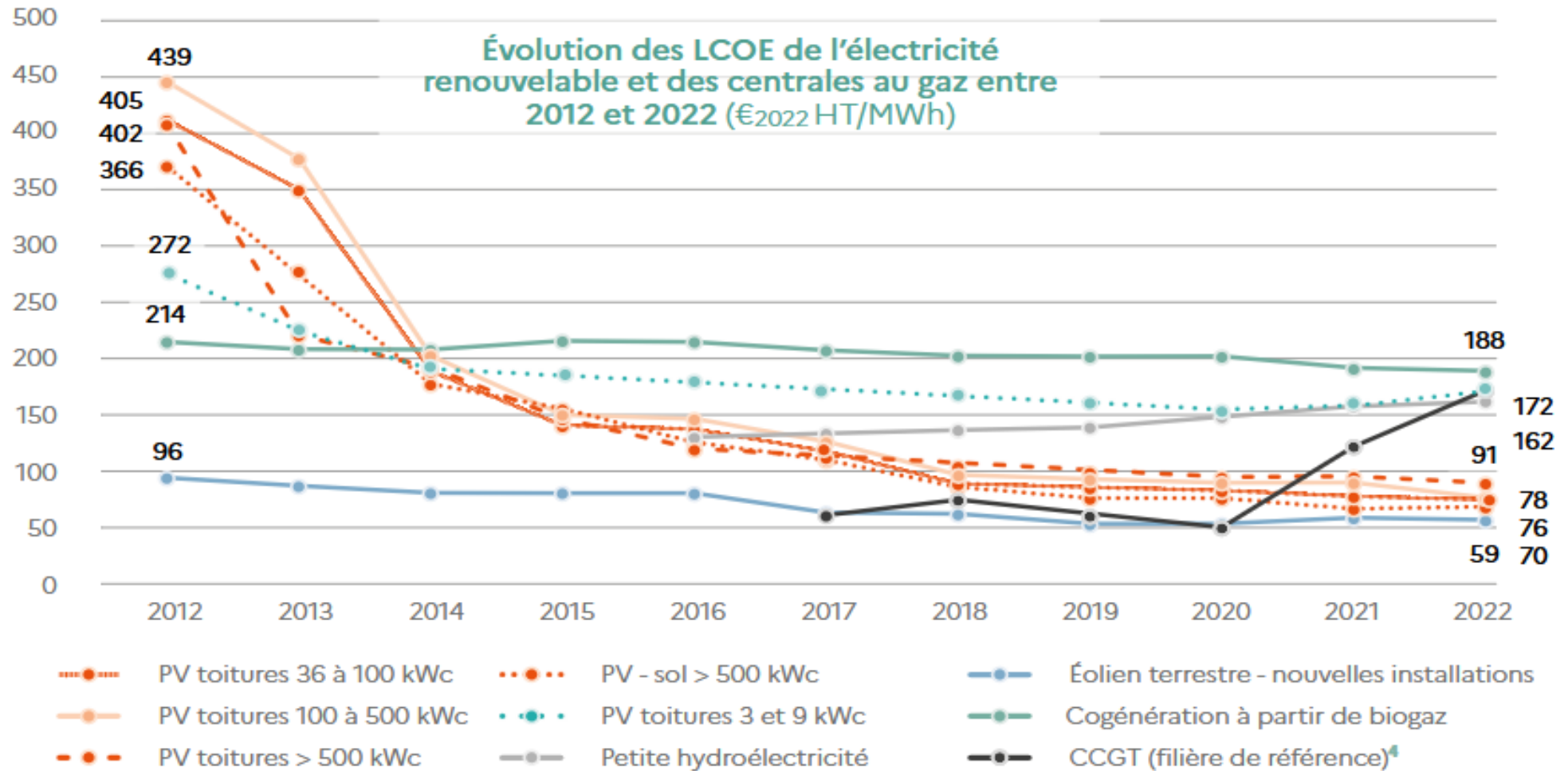
Remarque : le LCOE de la catégorie « PV toitures 3 et 9 kWc » correspond à la moyenne des LCOE calculés hors taxes des installations PV en injection de 3 kWc en IAB, 3 kWc en surimposition, de 9 kWc en ISB et de 9 kWc en surimposition.

Source: Ademe Edition 2024 – Janvier 2025

Nota: For CCGT, the gas price has very much increased from 2020 to 2022



France - LCOE of various Technologies – 2012 - 2022

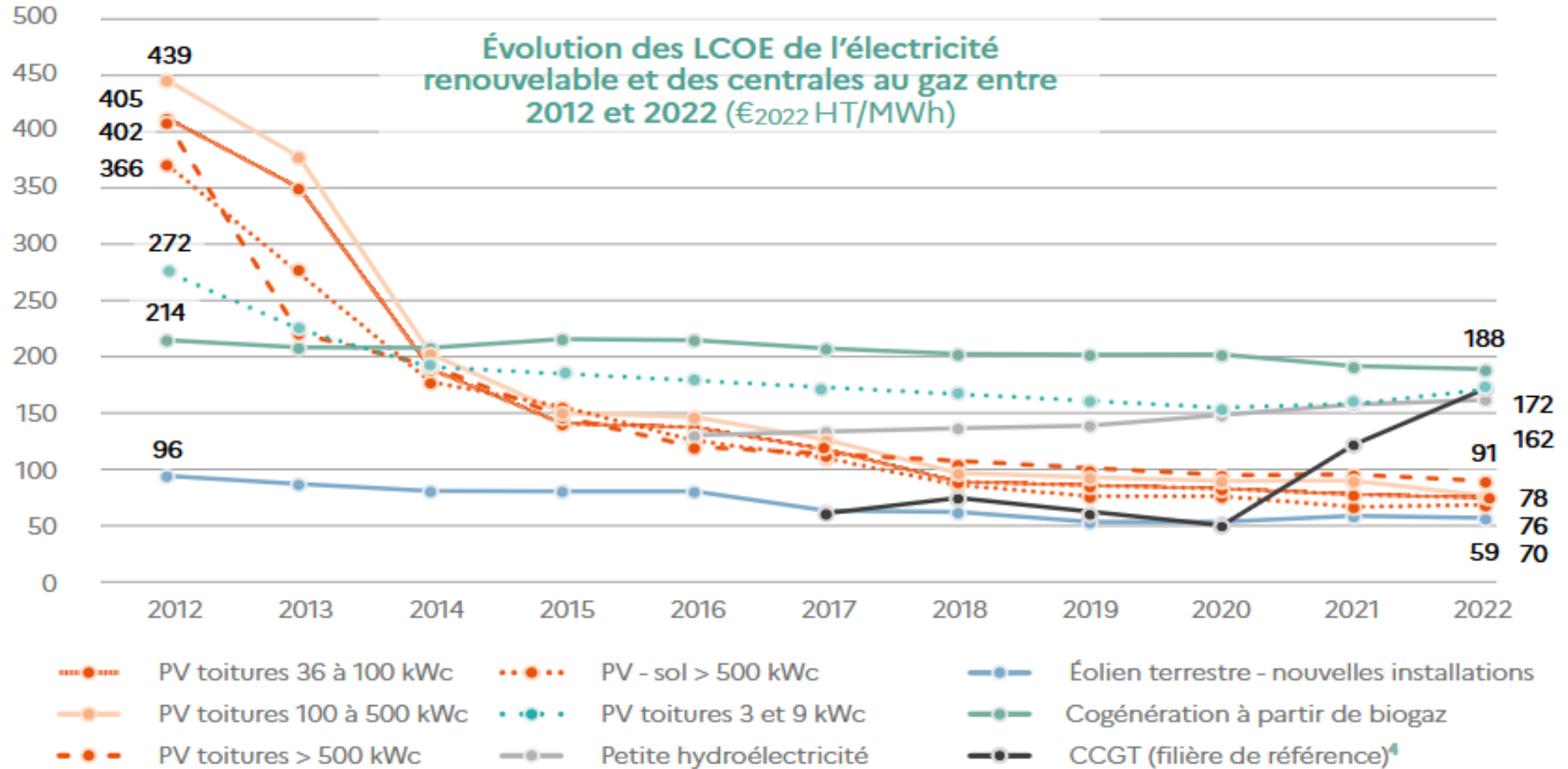


Source: Ademe Edition 2024 – Janvier 2025

Nota: For CCGT, the gas price has very much increased from 2020 to 2022



France - LCOE of various Technologies – 2012 - 2022

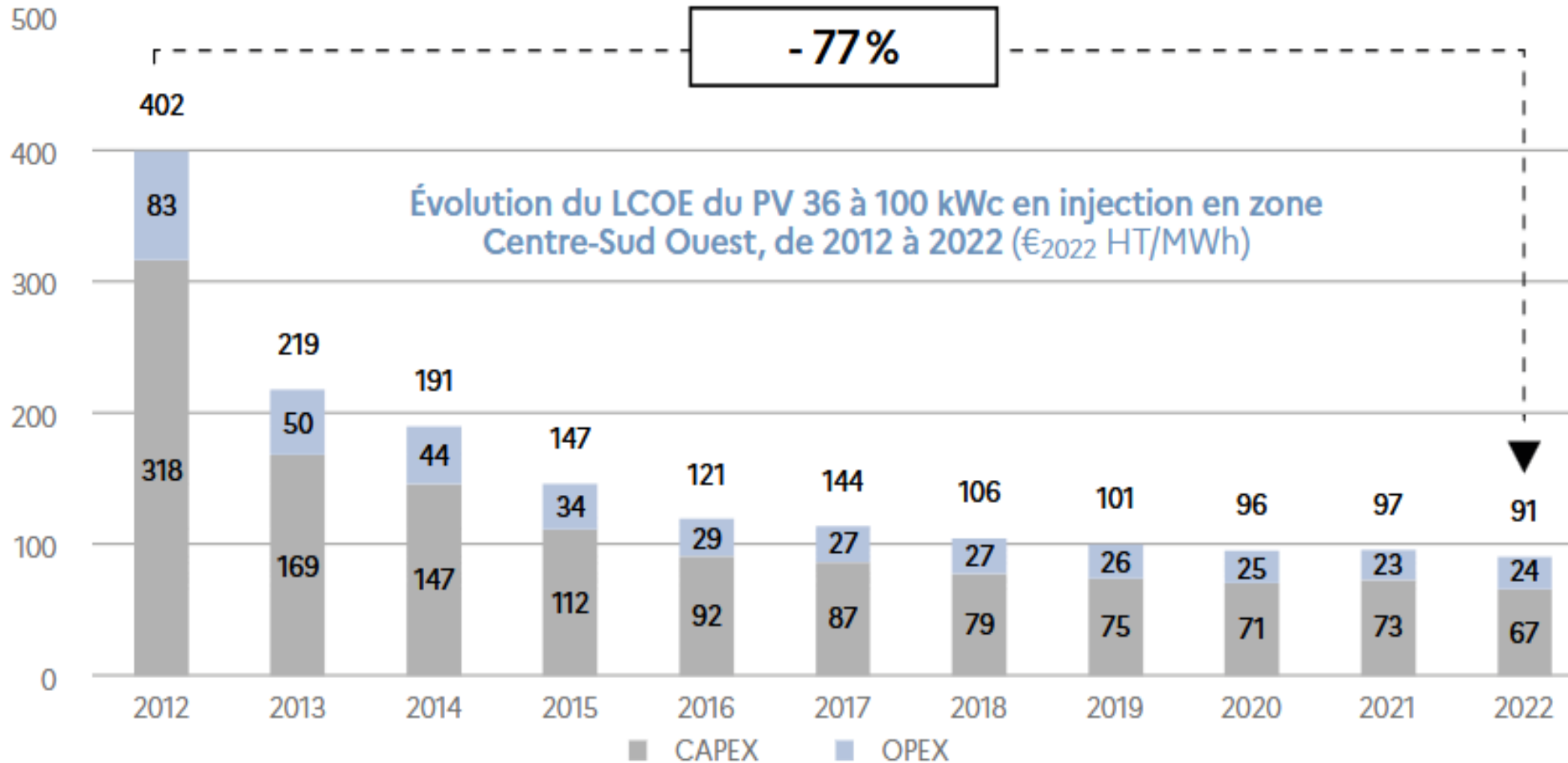


Source: Ademe Edition 2024 – Janvier 2025

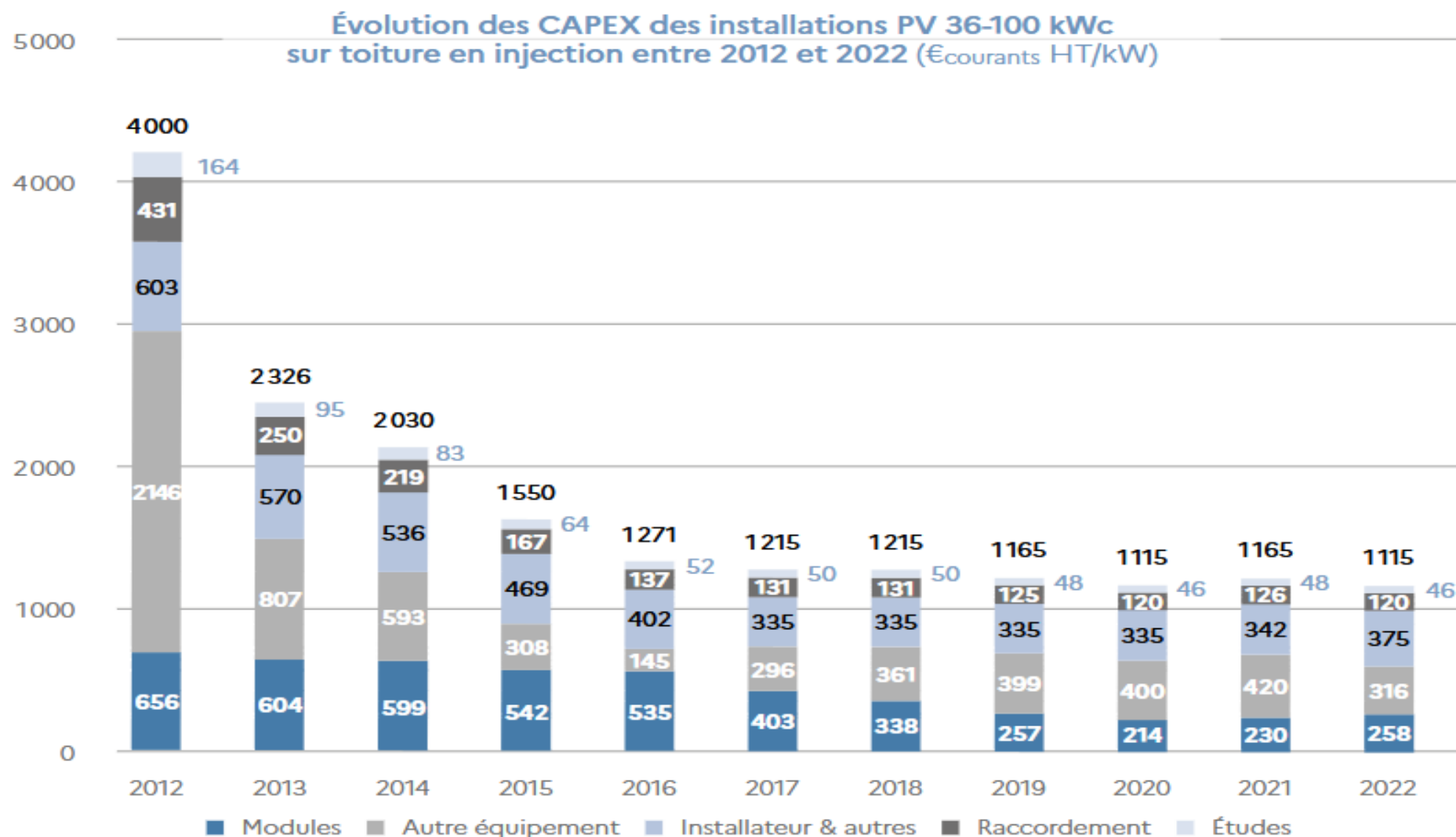
Nota: For CCGT, the gas price has very much increased from 2020 to 2022



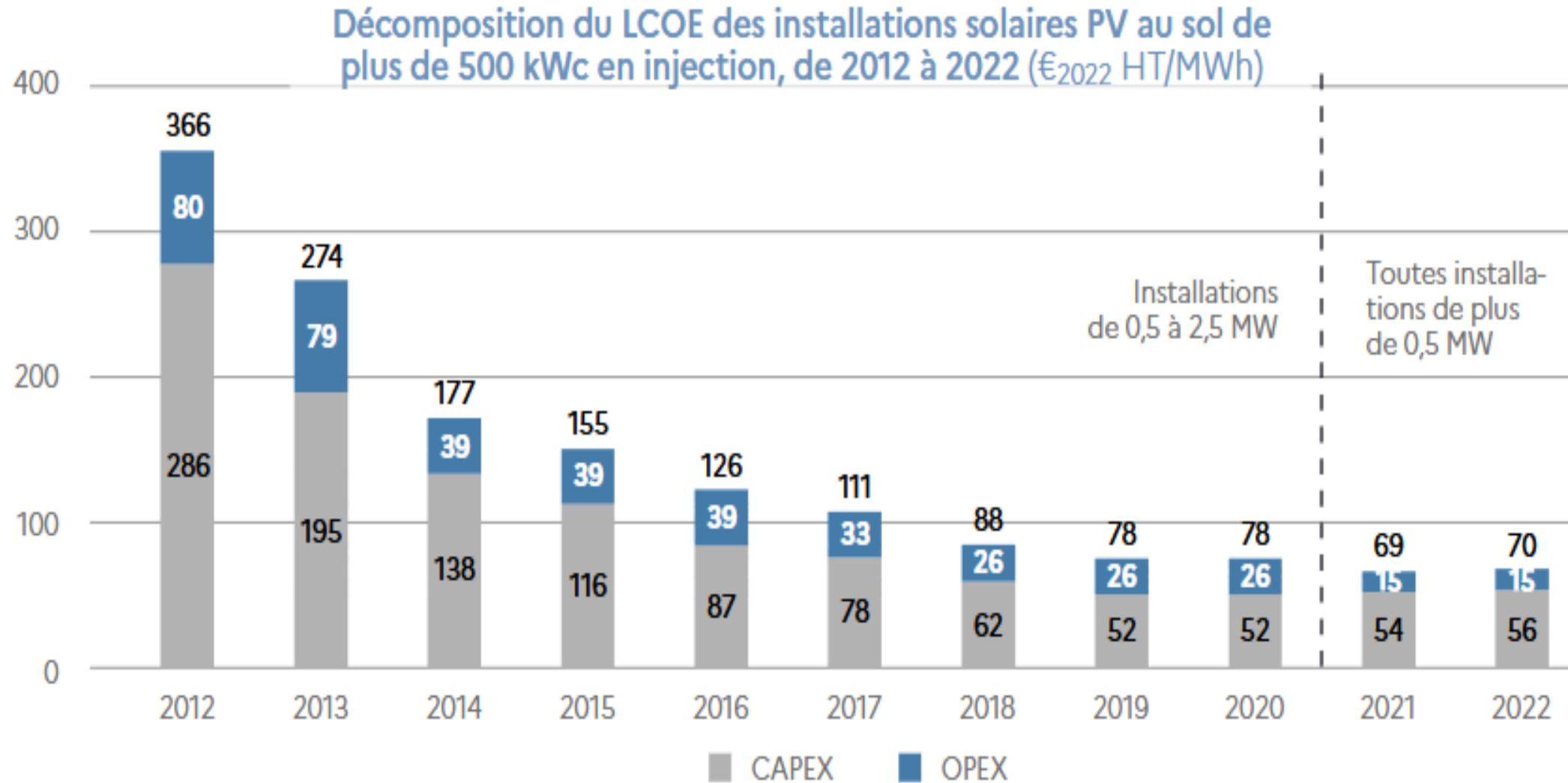
PV « Moyennes toitures » LCOE evolution



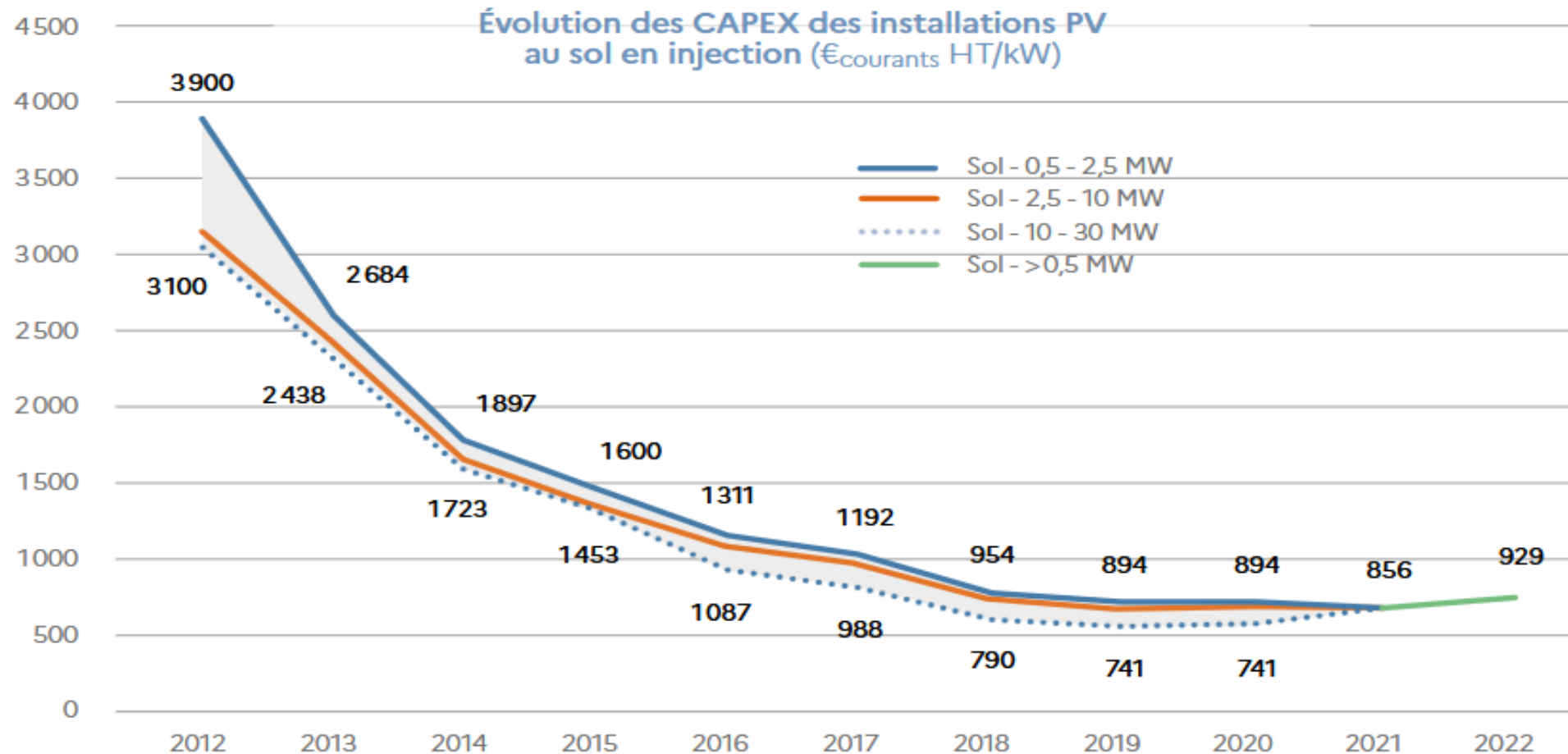
PV « Moyennes toitures » Capex evolution



PV au sol LCOE evolution



PV au sol Capex evolution

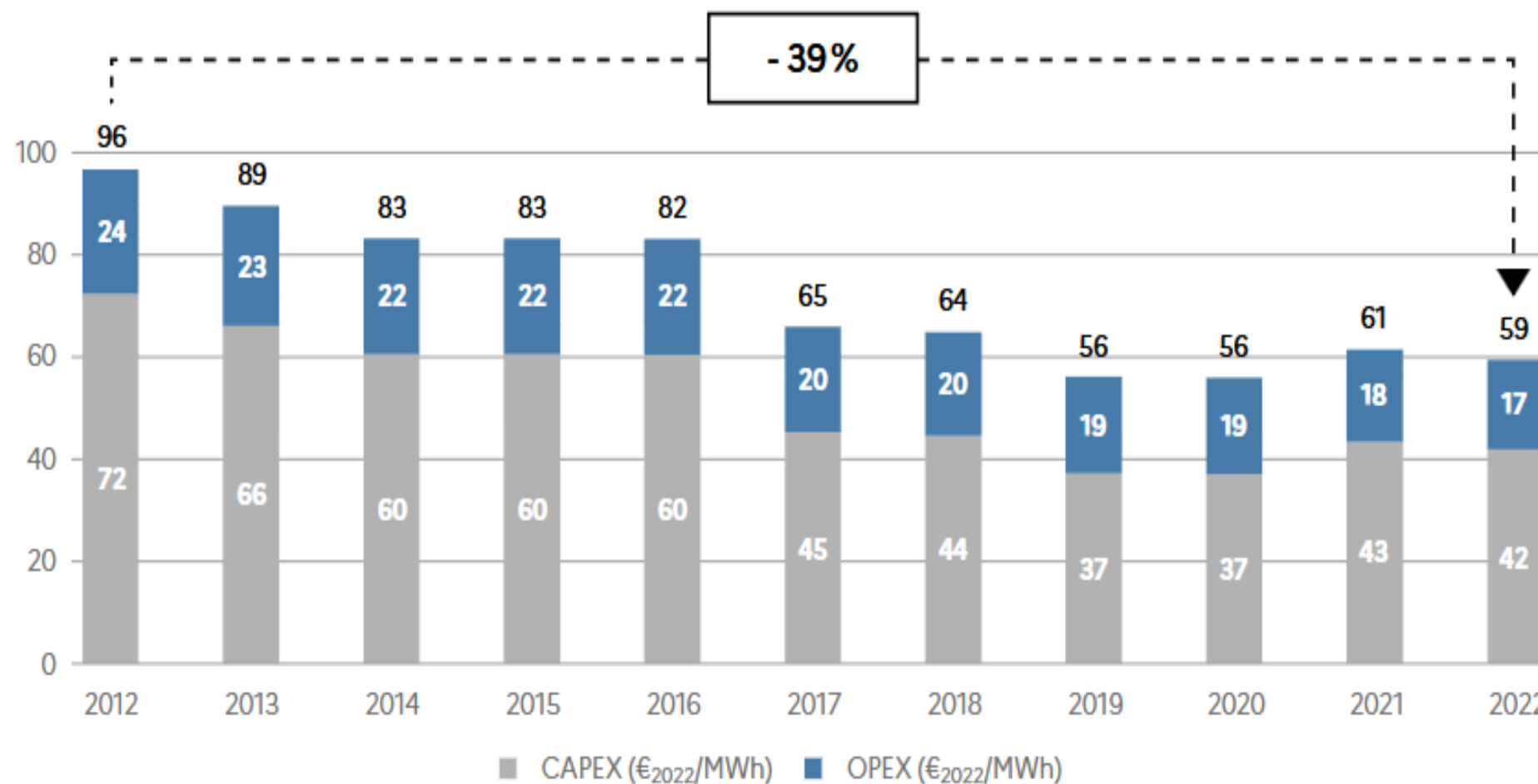


Remarque : De 2012 à 2020, les données par segments de puissance étaient disponibles et sont présentées dans le graphique. Pour 2021 et 2022, les sources de données présentent des coûts d'investissements pour une tranche de puissance unique (supérieure à 500 kWc).



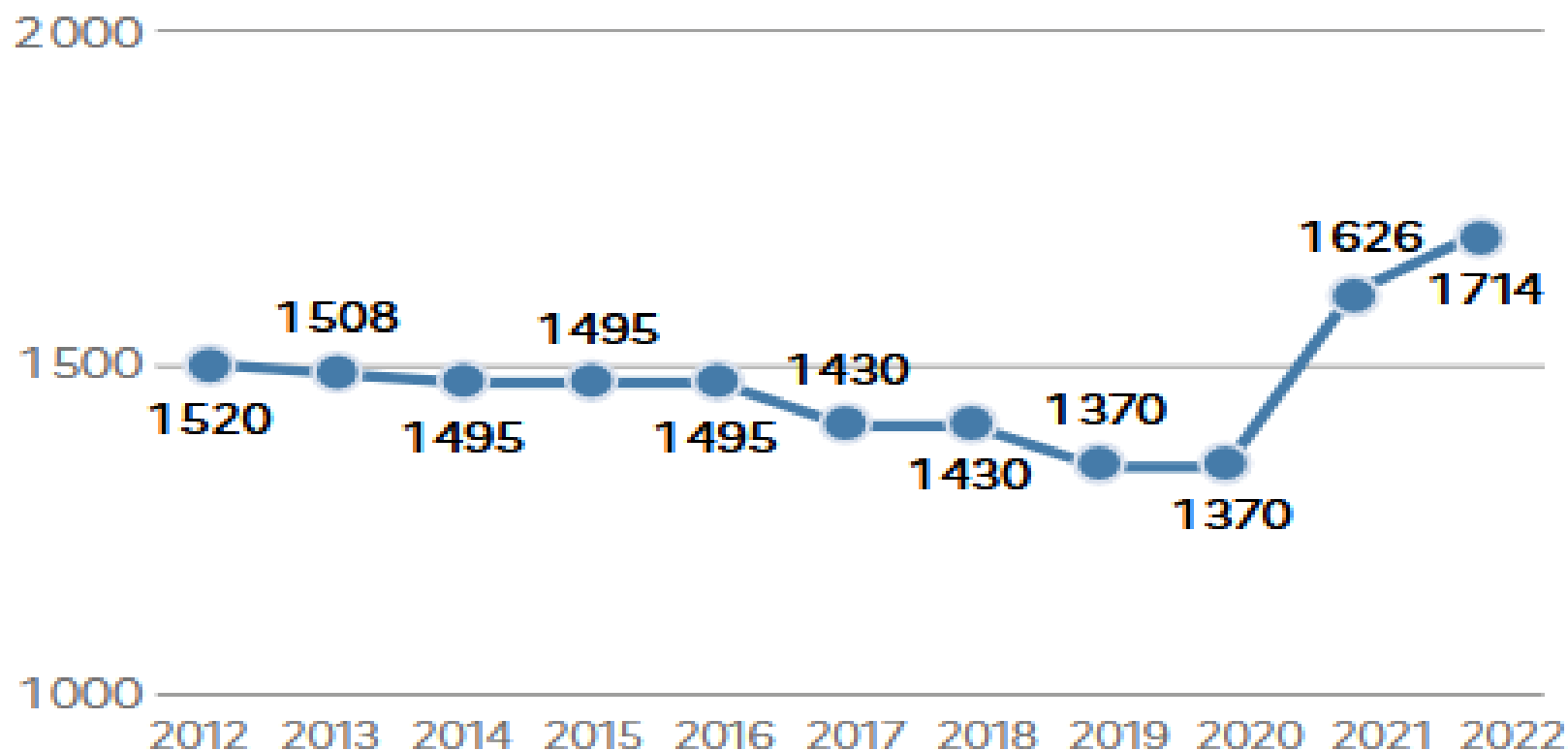
Wind onshore LCOE evolution

Évolution du LCOE de l'éolien terrestre de 2012 à 2022
pour les nouveaux parcs (€₂₀₂₂HT/MWh)



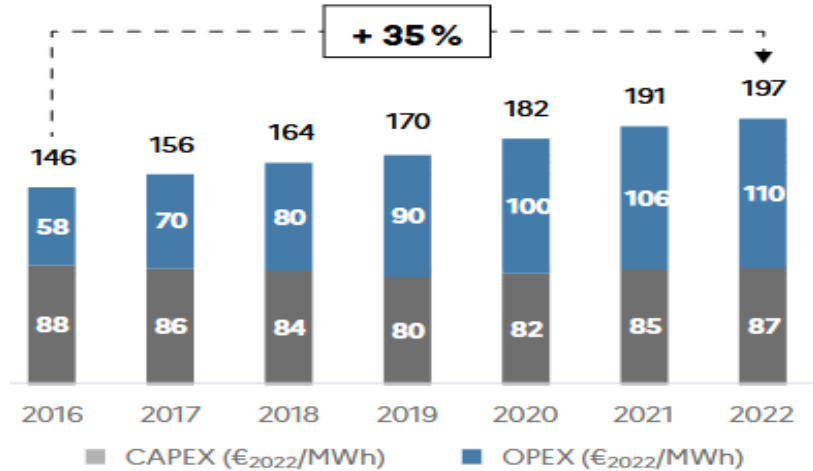
Wind onshore Capex evolution

Évolution des CAPEX des nouveaux parcs éoliens entre 2012 et 2022 (en €courants HT/kW)

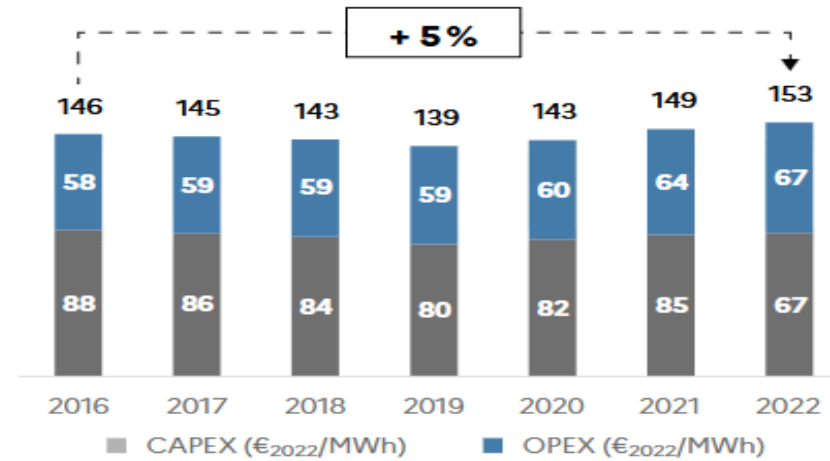


Small Hydroelectricity LCOE evolution

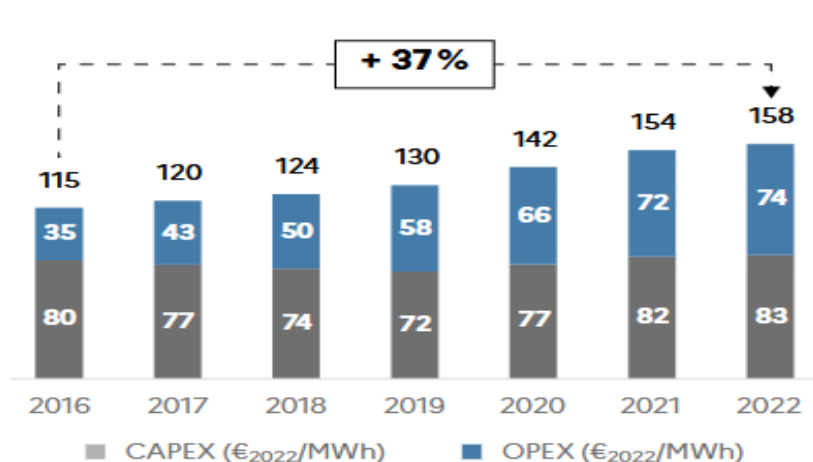
Évolution du LCOE des centrales basse chute
<1MW de 2016 à 2022 (€₂₀₂₂HT/MWh)



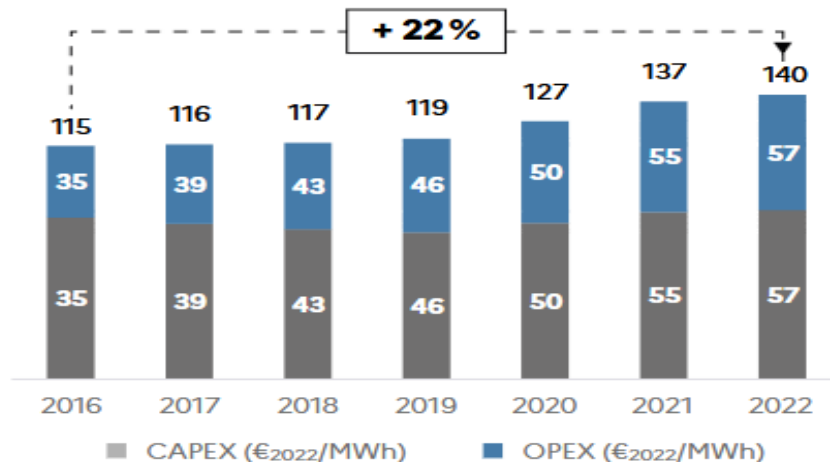
Évolution du LCOE des centrales haute chute
<1MW de 2016 à 2022 (€₂₀₂₂HT/MWh)



Évolution du LCOE des centrales basse chute
≥1MW de 2016 à 2022 (€₂₀₂₂HT/MWh)

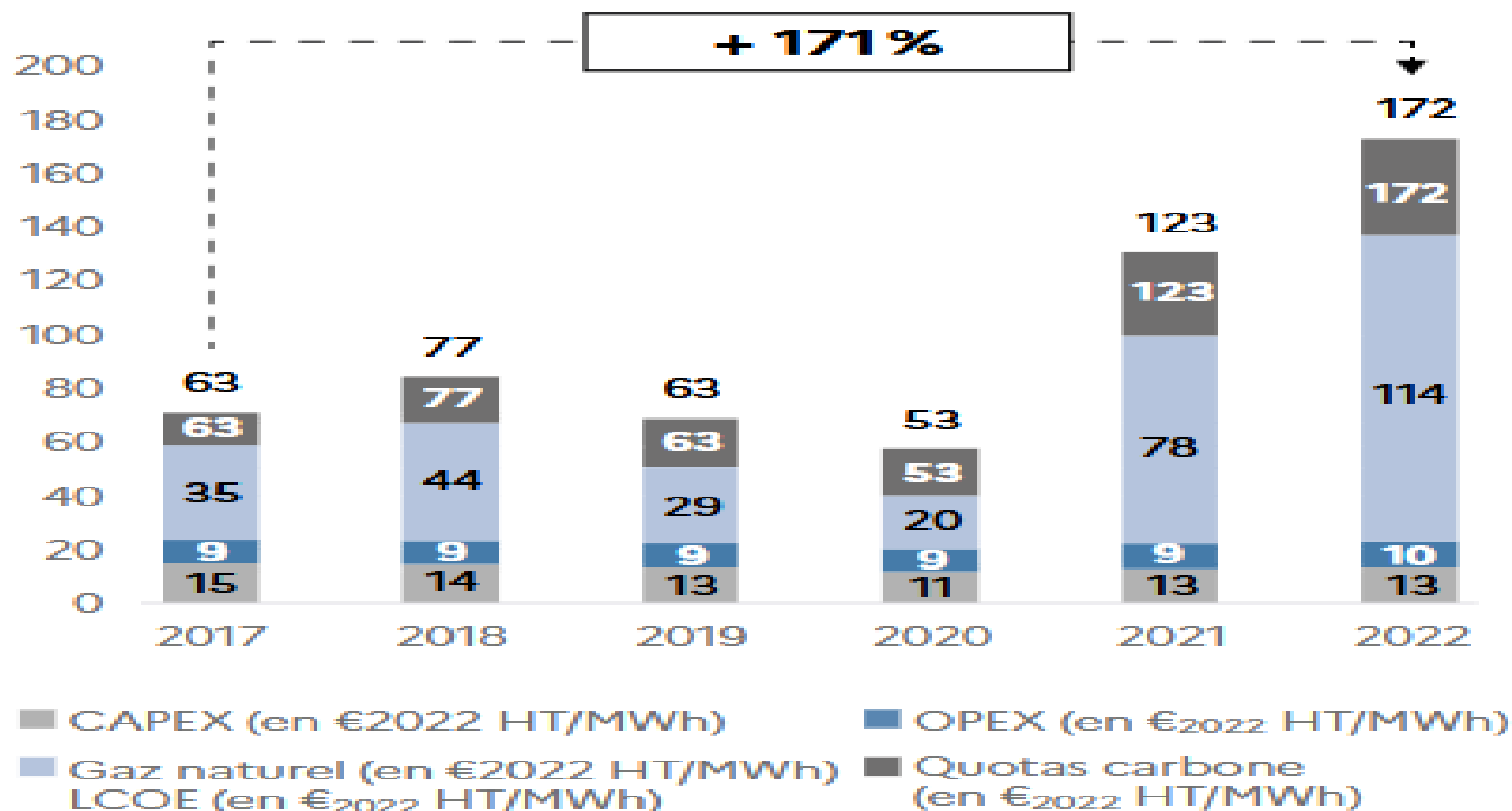


Évolution du LCOE des centrales haute chute
≥1MW de 2016 à 2022 (€₂₀₂₂HT/MWh)



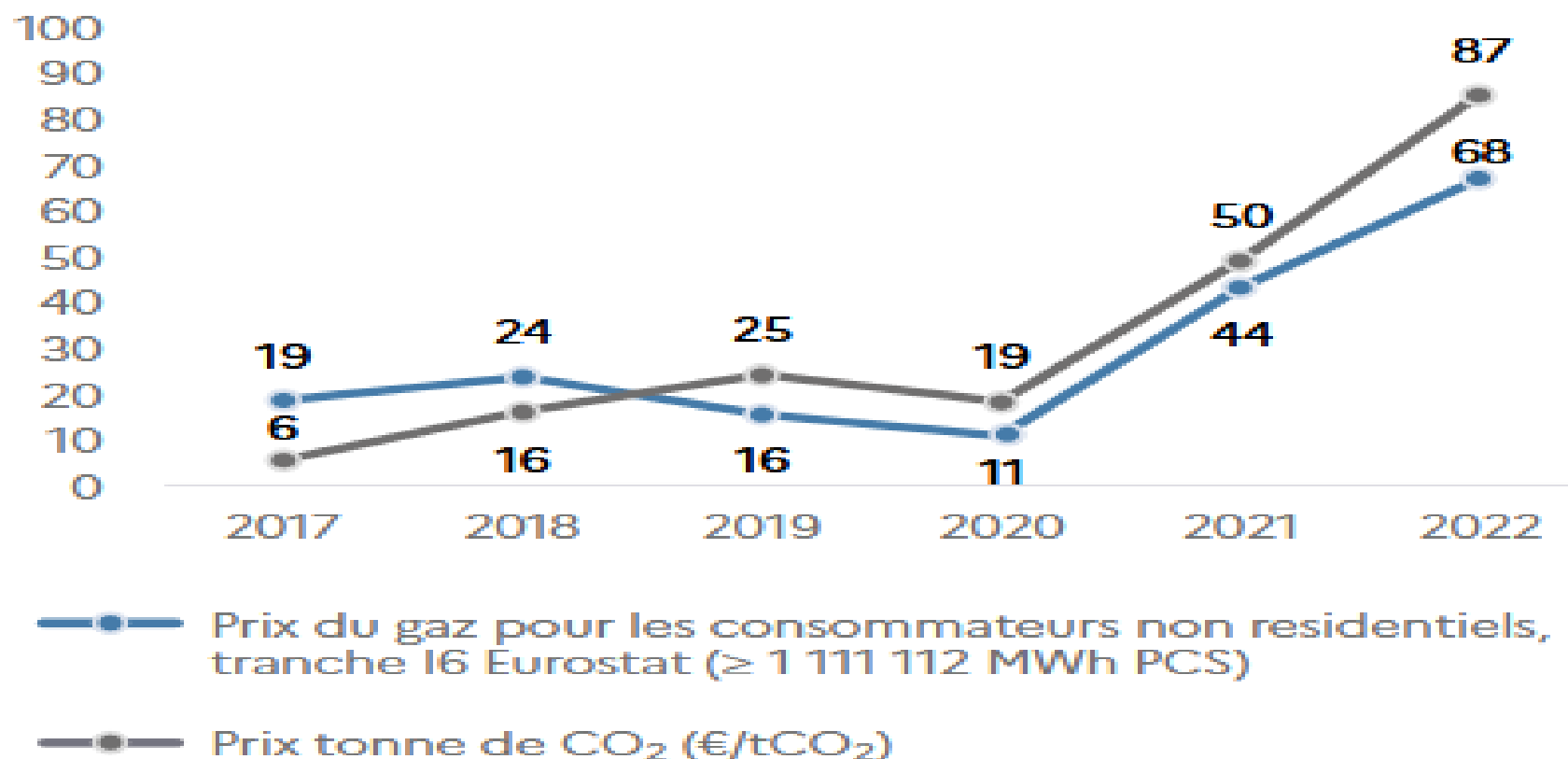
Gas Power plant CCGT LCOE evolution

Évolution du LCOE des centrales à cycle combiné au gaz (CCGT) de 2012 à 2022
(€₂₀₂₂ HT/MWh)



Gas Power plant CCGT - Impact of Gas Price & Carbon Price

Évolution du prix du gaz naturel pour les gros consommateurs industriels (en €/HT/MWh) et du prix du carbone (en €/t CO₂)



1-9

TotalEnergies Positionning

**(See Book 2 Energy, Chapter 7
& Book 4 Oil, Chapter 13)**





Neptune Floating Storage and Regasification Unit (FSRU) – Turkey



TotalEnergies

TotalEnergies Energy Outlook 2025

November 4th, 2025



1-10

**A Challenge:
The Criticality of Mineral Materials & Rare
Earth Elements Resources
(See Book 2 Energy, Chapter 14)**



The Criticality of Mineral Materials & Rare Earth Elements



Periodic Table of Elements

1A 1 **H** hydrogen 1.008

2A 4 **Be** beryllium 9.012

3 3 **Li** lithium 6.94

11 11 **Na** sodium 22.99

19 19 **K** potassium 39.10

37 37 **Rb** rubidium 85.47

55 55 **Cs** cesium 132.9

87 87 **Fr** francium (223)

2 2 **He** helium 4.003

10 10 **Ne** neon 20.18

18 18 **Ar** argon 39.95

36 36 **Kr** krypton 83.79

54 54 **Xe** xenon 131.3

86 86 **Rn** radon (222)

118 118 **Uuo** (294)

3A 5 **B** boron 10.81

13 13 **Al** aluminum 26.98

31 31 **Ga** gallium 69.72

49 49 **In** indium 114.8

67 67 **Ho** holmium 164.9

85 85 **At** astatine (210)

103 103 **Lr** lawrencium (260)

4A 6 **C** carbon 12.01

14 14 **Si** silicon 28.09

32 32 **Ge** germanium 72.64

50 50 **Sn** tin 118.7

68 68 **Er** erbium 167.3

86 86 **Bk** berkelium (247)

104 104 **Lv** livermorium (293)

5A 7 **N** nitrogen 14.01

15 15 **P** phosphorus 30.97

33 33 **As** arsenic 74.92

51 51 **Sb** antimony 121.8

69 69 **Tm** thulium 168.9

87 87 **Yb** ytterbium 173.0

105 105 **No** nobelium (259)

6A 8 **O** oxygen 16.00

16 16 **S** sulfur 32.06

34 34 **Se** selenium 78.96

52 52 **Te** tellurium 127.6

70 70 **Yb** ytterbium 173.0

88 88 **Ra** radium (226)

106 106 **Lr** lawrencium (260)

7A 9 **F** fluorine 18.99

17 17 **Cl** chlorine 35.45

35 35 **Br** bromine 79.90

53 53 **I** iodine 126.9

71 71 **Lu** lutetium 175.0

89 89 **Ac** actinium (227)

107 107 **Bh** bohrium (264)

117 117 **Uus** (294)

3B 21 **Sc** scandium 44.96

39 39 **Y** yttrium 88.91

57 57 **La** lanthanum 138.9

72 72 **Hf** hafnium 178.5

88 88 **Ra** radium (226)

104 104 **Rf** rutherfordium (261)

4B 22 **Ti** titanium 47.88

40 40 **Zr** zirconium 91.22

58 58 **Ce** cerium 140.1

74 74 **Ta** tantalum 180.9

90 90 **Th** thorium 232

105 105 **Db** dubnium (268)

5B 23 **V** vanadium 50.94

41 41 **Nb** niobium 92.91

59 59 **Pr** praseodymium 140.9

75 75 **W** tungsten 183.8

91 91 **Pa** protactinium 231

106 106 **Sg** seaborgium (266)

6B 24 **Cr** chromium 52.00

42 42 **Mo** molybdenum 95.94

60 60 **Nd** neodymium 144.2

76 76 **Os** osmium 190.2

92 92 **U** uranium 238

107 107 **Bh** bohrium (264)

7B 25 **Mn** manganese 54.94

43 43 **Tc** technetium (98)

61 61 **Pm** promethium (145)

77 77 **Ir** iridium 192.2

93 93 **Np** neptunium (237)

108 108 **Hs** hassium (277)

8B 26 **Fe** iron 55.85

44 44 **Ru** ruthenium 101.1

62 62 **Sm** samarium 150.4

78 78 **Pt** platinum 195.1

94 94 **Pu** plutonium (244)

109 109 **Mt** meitnerium (268)

11B 29 **Cu** copper 63.55

47 47 **Ag** silver 107.9

63 63 **Eu** europium 152.0

79 79 **Au** gold 197.0

95 95 **Am** americium (243)

110 110 **Ds** darmstadtium (281)

12B 30 **Zn** zinc 65.39

48 48 **Cd** cadmium 112.4

64 64 **Gd** gadolinium 157.3

80 80 **Hg** mercury 200.6

96 96 **Cm** curium (247)

111 111 **Rg** roentgenium (280)

112 112 **Cn** copernicium (285)

113 113 **Uut** (294)

114 114 **Fl** flerovium (289)

115 115 **Uup** (293)

116 116 **Lv** livermorium (293)

117 117 **Uus** (294)

118 118 **Uuo** (294)

Lanthanide Series*

Actinide Series**

Los Alamos NATIONAL LABORATORY

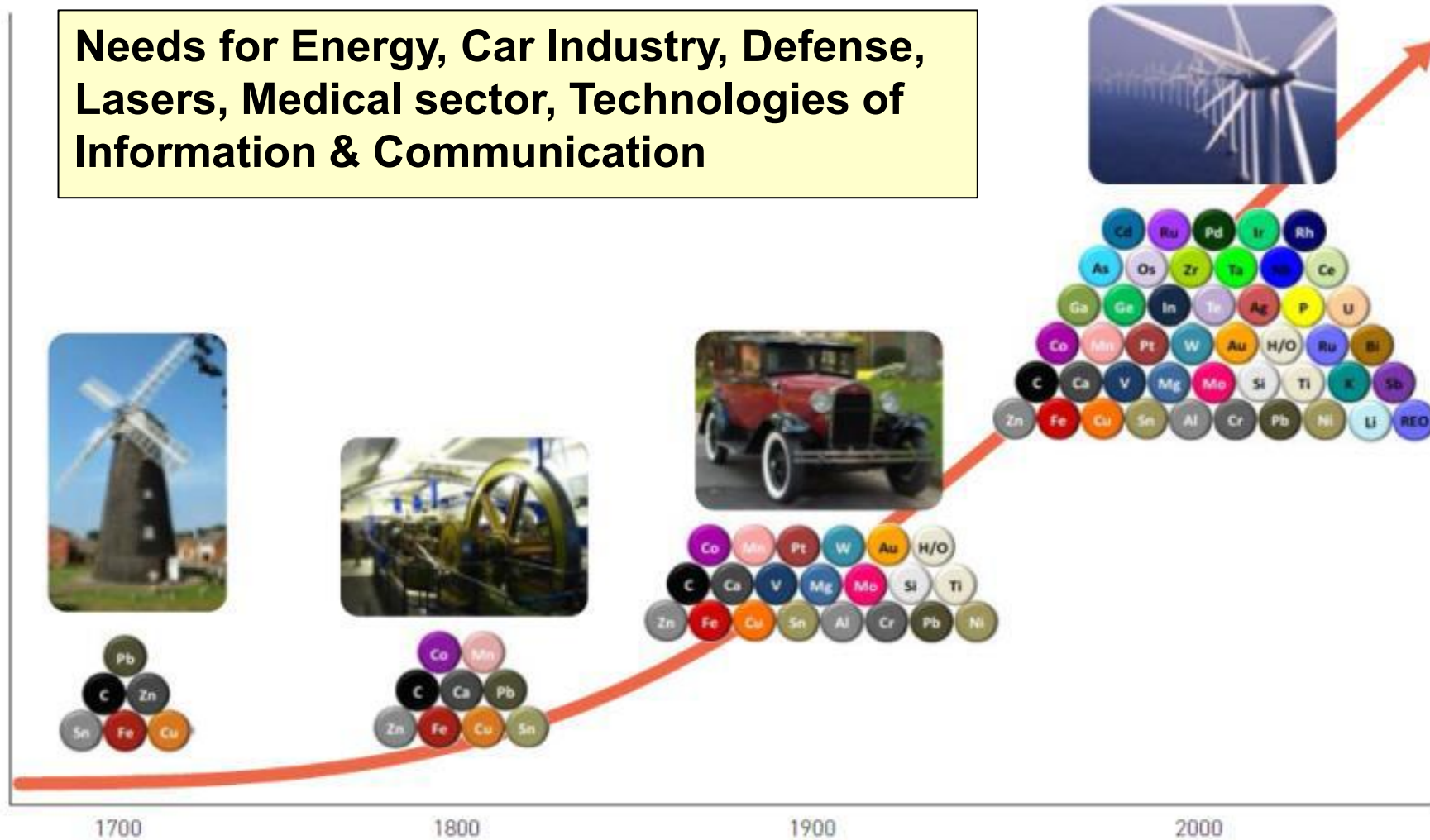
CHEMISTRY

element names in blue are liquids at room temperature
element names in red are gases at room temperature
element names in black are solids at room temperature



More and more Materials are needed for Industry

Needs for Energy, Car Industry, Defense, Lasers, Medical sector, Technologies of Information & Communication



1-11

Dismantlement and Recycling



A Challenge: The Treatment of Dismantlement and Recycling of Renewables Energy Equipment



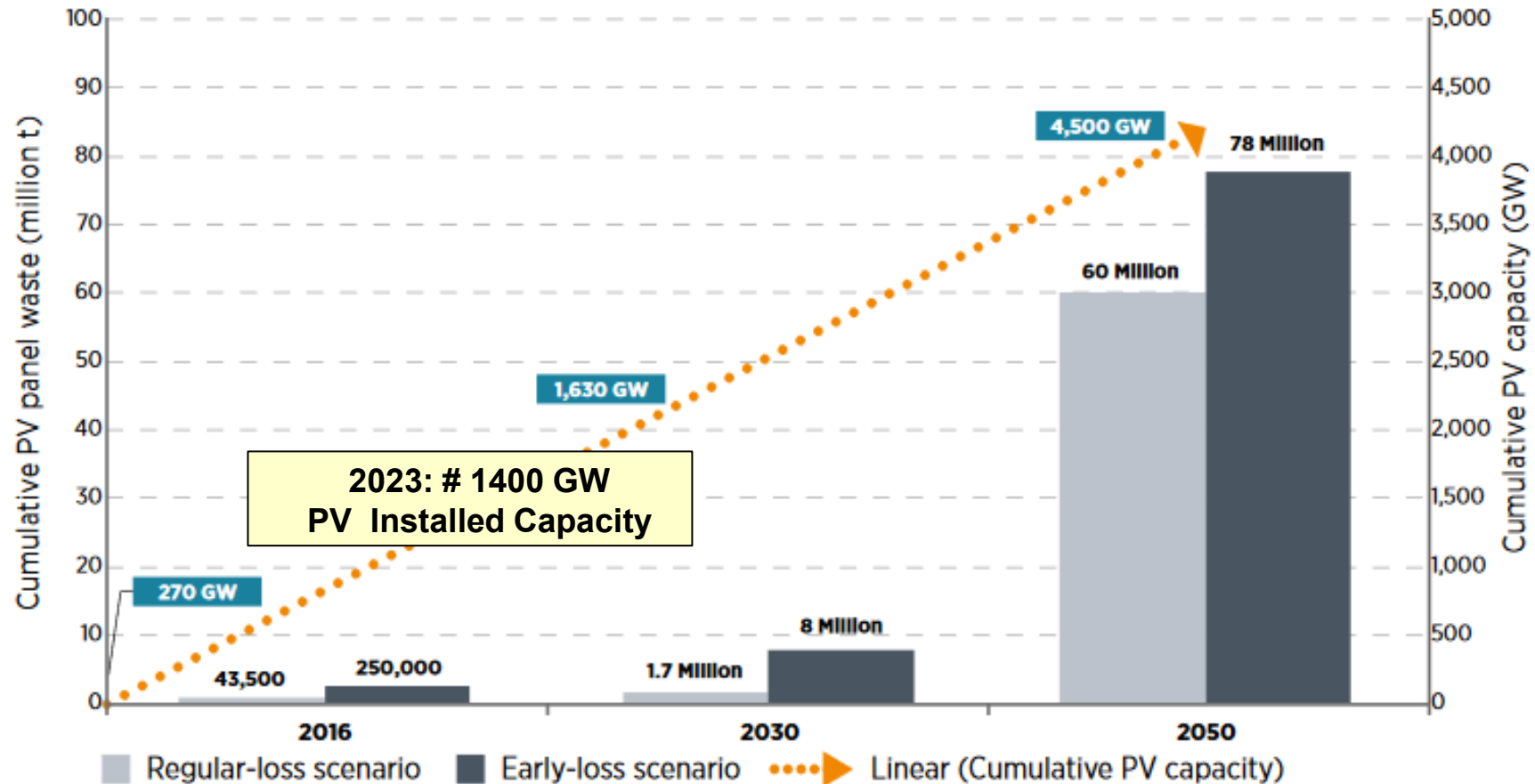
Recycling of Renewables Energy End Life Equipment – Example: Solar PV

- **Recycling requires separating and recovering materials that contain: aluminium frames, silicon solar panels, plastic, glass covers, metals (cadmium, copper, lead, gallium, tellurium, indium,....)**
- **One tool: Legislation on Management of WEEE (Waste of Electric and Electronic Equipment)**
- **# 96% of Waste can be recycled**
 - ☐ **Glass can be indefinitely reused for multiple purposes**
 - ☐ **Aluminium can be reused for all types of aluminium based equipment.**
 - ☐ **Silicium can be reused 4 times to fabricate new solar panels or be incorporated in other electronic products**
 - ☐ **Copper & silver can be reused for multiple applications**
 - ☐ **Plastic is not recycleable. It is burned.**



Recycling of Renewables Energy Equipment – Example: Solar PV

Overview of global PV panel waste projections, 2016-2050

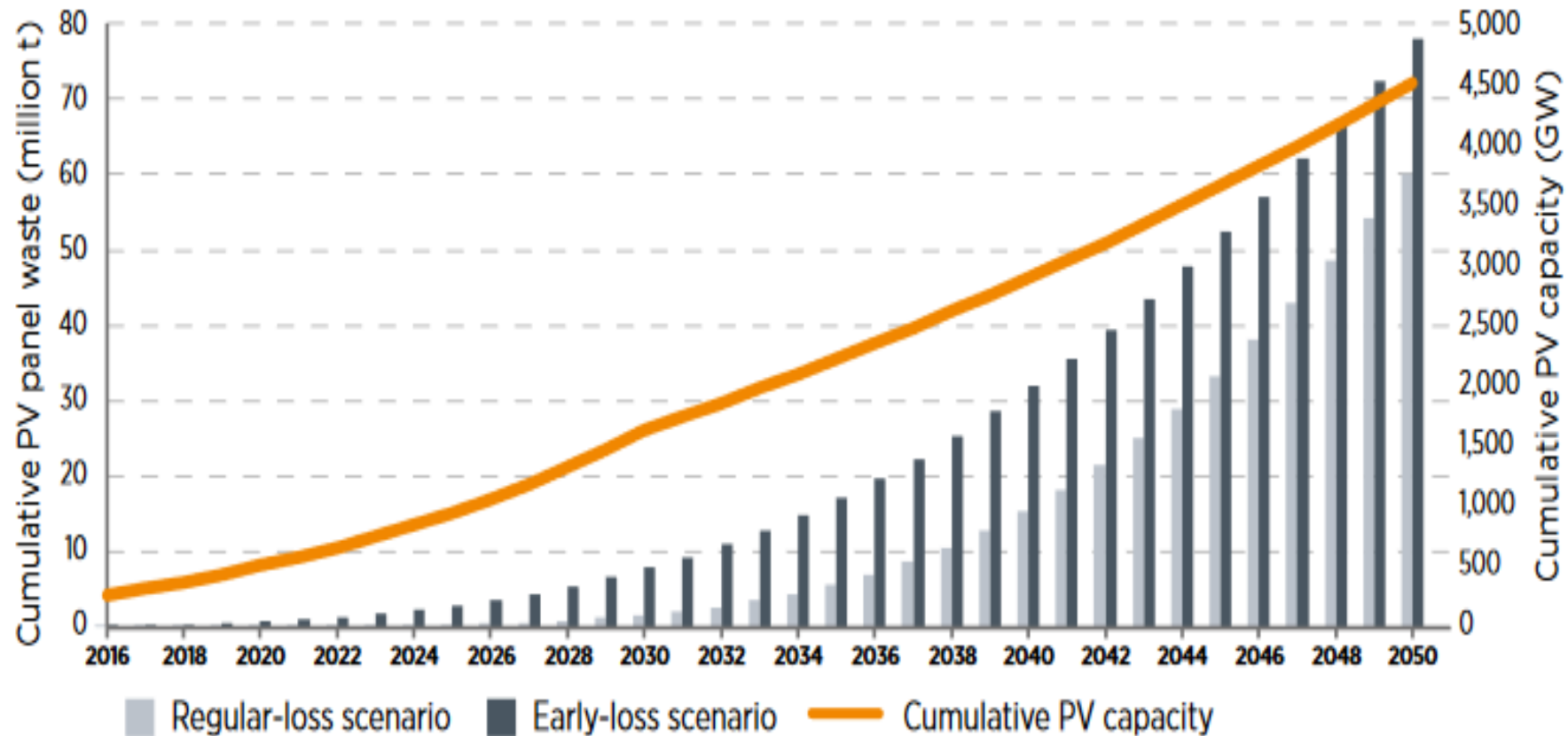


Source: IRENA/IEA 2016
End of Life Management – Solar PV Panels



Recycling of Renewables Energy Equipment – Example: Solar PV

Estimated cumulative global waste volumes (million t) of end-of-life PV panels

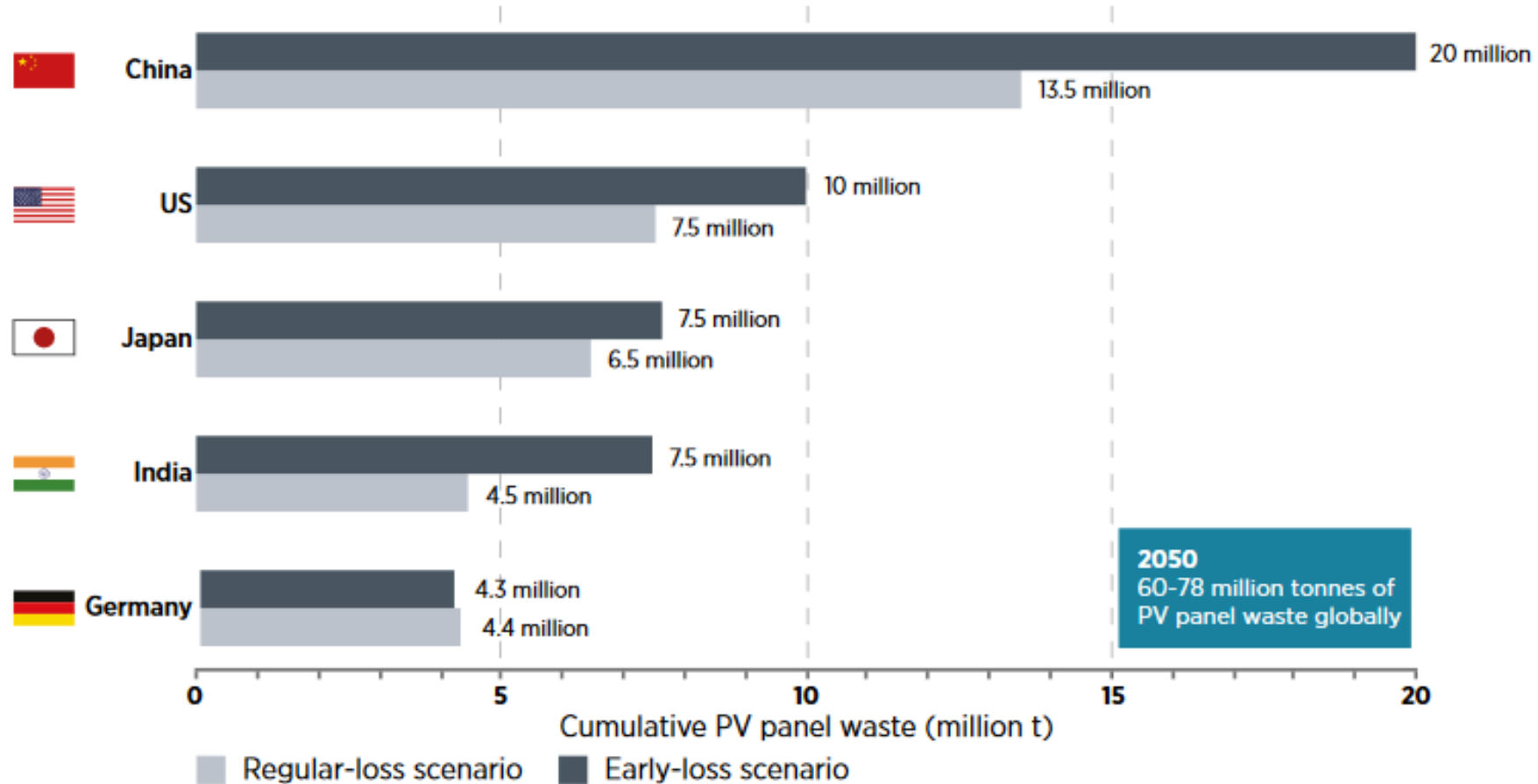


Source: IRENA/IEA 2016
End of Life Management – Solar PV Panels



Recycling of Renewables Energy Equipment – Example: Solar PV

Cumulative waste volumes of top five countries for of end-of-life PV panels in 2050

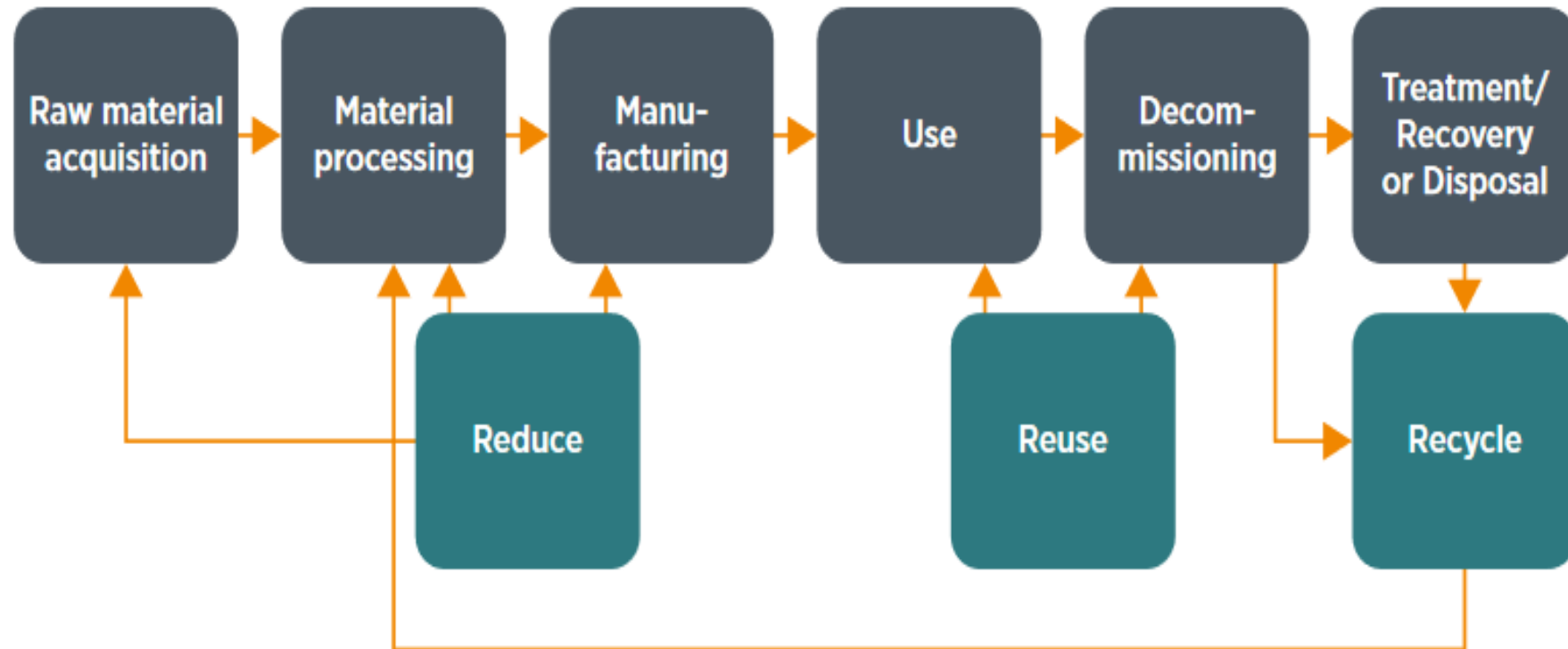


Source: IRENA/IEA 2016
End of Life Management – Solar PV Panels



Recycling of Renewables Energy Equipment – Example: Solar PV

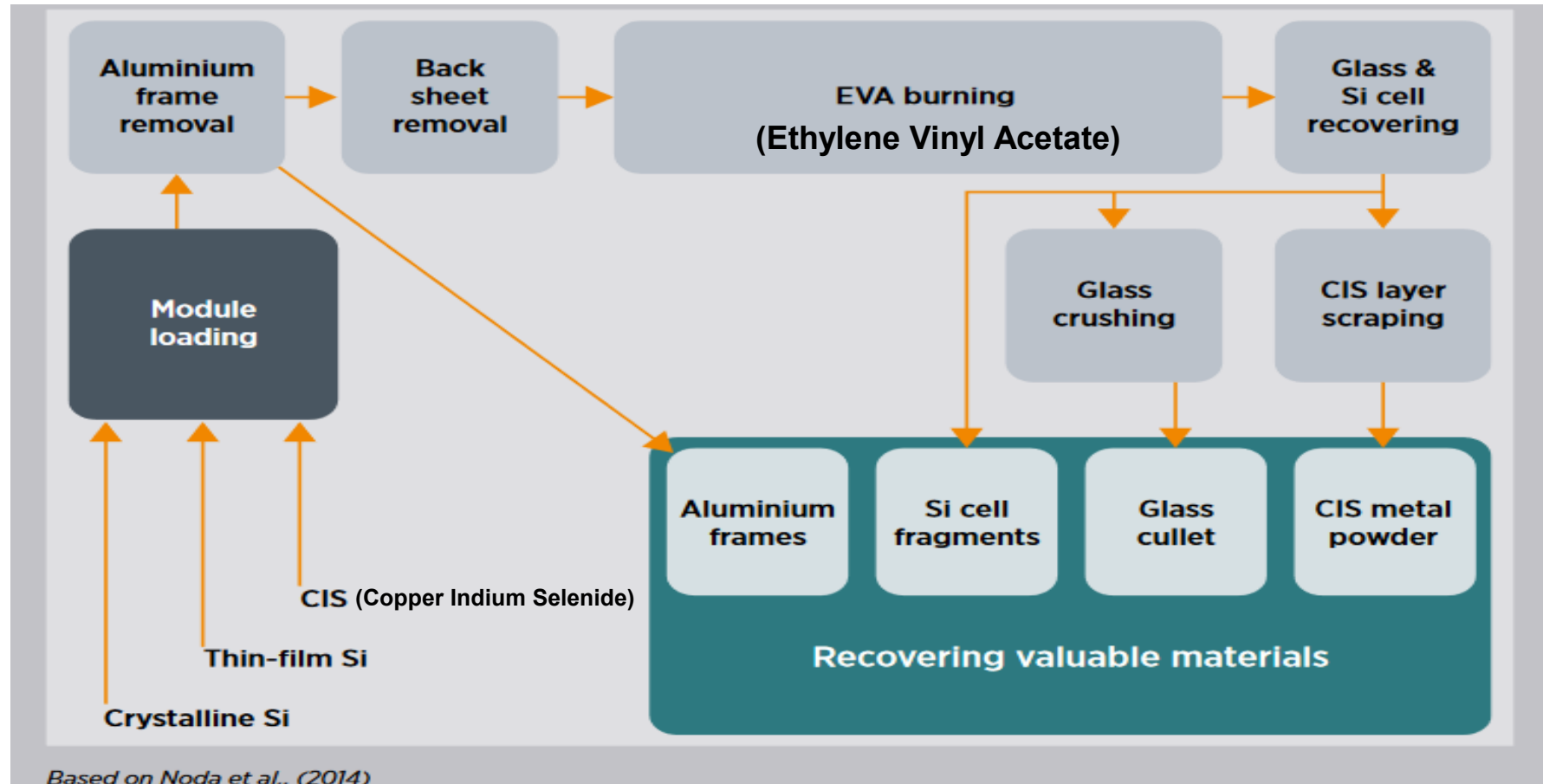
Process flow diagram of the life cycle stages for PV panels and resulting opportunities



Adapted from Fthenakis (2000)

Recycling of Renewables Energy Equipment – Example: Solar PV

PV Panels Recycling System



Based on Noda et al., (2014)

Source: IRENA/IEA 2016
End of Life Management – Solar PV Panels

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TPA Toolbox Energy Book 7 – Renewables

Recycling Plant Solar PV panels – Saint-Loubès/France

Since 2015, 20000 solar panels have been recycled



Recycling of Renewables Energy End Life Equipment – Example: Wind Turbines

- **Unfortunately, decommissioning and recycling Wind Turbines is still a kind of blindspot and is not the subject of thorough analysis by the Wind Energy industry.**
- **Many Wind Turbines components – tower and foundation, generator and gearbox are manufactured from materials that are recyclable and have good scrap value (Steel and Copper) The recycling rate can reach 85/90%.**
- **Wind Turbines blades, made from composite material (fiber-reinforced epoxy or unsaturated polyester) are more problematic. They can be recycled through cement co-processing**
- **Additional solutions could be to cutting the blades into pieces that are refined by grinding and milling and processed into new composite materials which can be used in other applications.**





BOOK 7 - TABLE OF CONTENTS

1. Global Remarks on Renewable Energy Sources

- Renewables in the Energy Mix –Trends/Perspectives – Investments – Potential/Diffusion/Network – Subsidies – Intermittency – Competitiveness – France PPE – Total Positioning – Criticality of Mineral Matters Resources – Dismantelment/End Life Equipment Recycling

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5. Geothermal Energy

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- 1. Wind Technology Fundamentals**
- 2. Wind Energy Markets**
- 3. Offshore Wind Energy**
- 4. Wind Energy the approach of TotalEnergies**
- 5. Wind Economics Fundamentals**

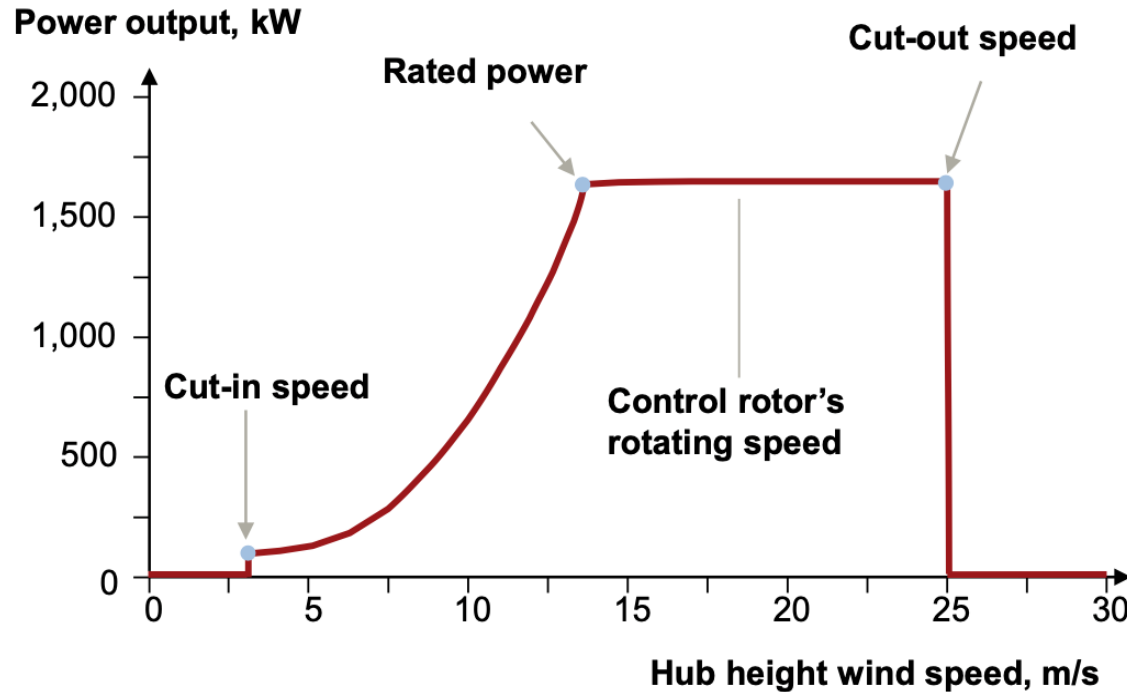


2-1

Wind Technology Fundamentals



Conceptual power curve of a wind turbine



Power received from the wind turbine is equal to kinetic energy of wind flow through the rotor period of time

$$P(v) = \frac{1}{2} \rho v^3$$

Air density $\rho = 1.225 \text{ kg/m}^3$
 v = wind velocity
 P = power

Note: m/s is meters per second.

Source: A.T. Kearney Energy Transition institute; IPCC (2011), "Special report on renewable energy"

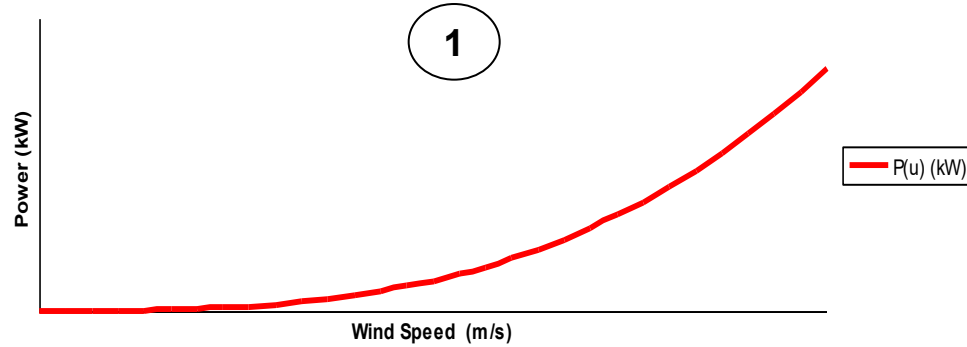
How to read this graph

- **Cut-in speed:** rotors start extracting energy from the wind at a defined speed, the cut-in speed (usually ~3 to 4 m/s).
- **Rated power:** power production increases with wind speed until it reaches its rated power level (usually ~11 to 15 m/s). The energy available in the wind is a function of the cube of the wind speed.
- **Controlled speed:** after rated power, control systems limit power output to avoid overloading the wind turbine through stall control, pitching the blades, or a combination of both (see appendix).
- **Cut-out speed:** most turbines stop producing at a defined speed to limit loads on the rotor and prevent damage to the turbine (usually ~20 to 25 m/s). The blades are feathered and the gearbox is locked (see appendix).

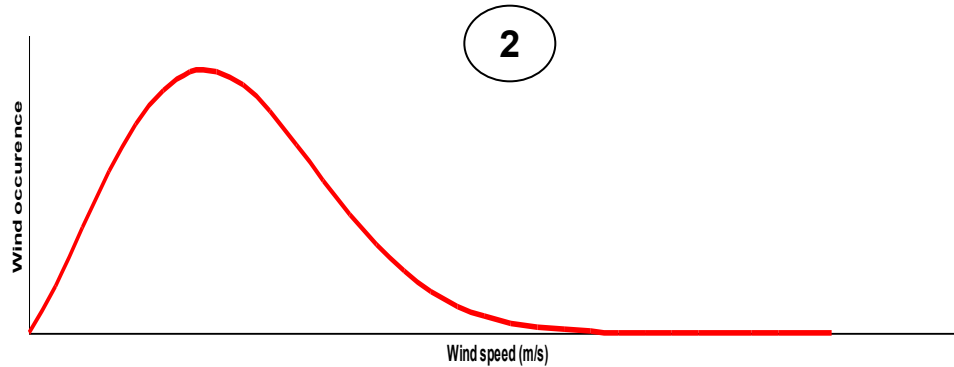


Wind energy resource

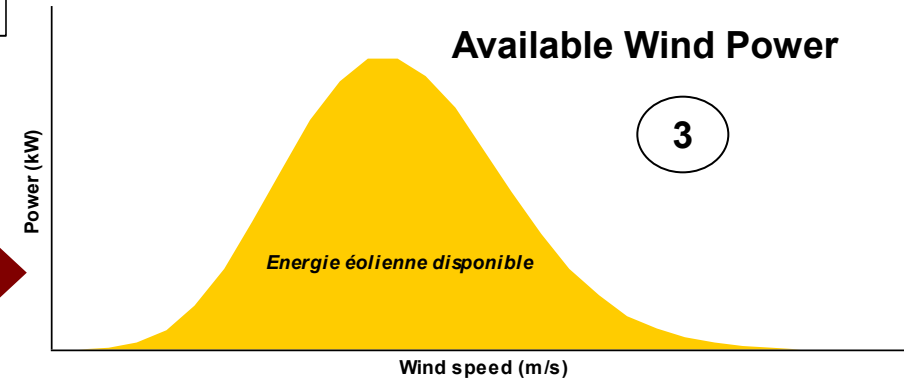
Wind speed and POWER



Wind speed distribution



Available Wind Power

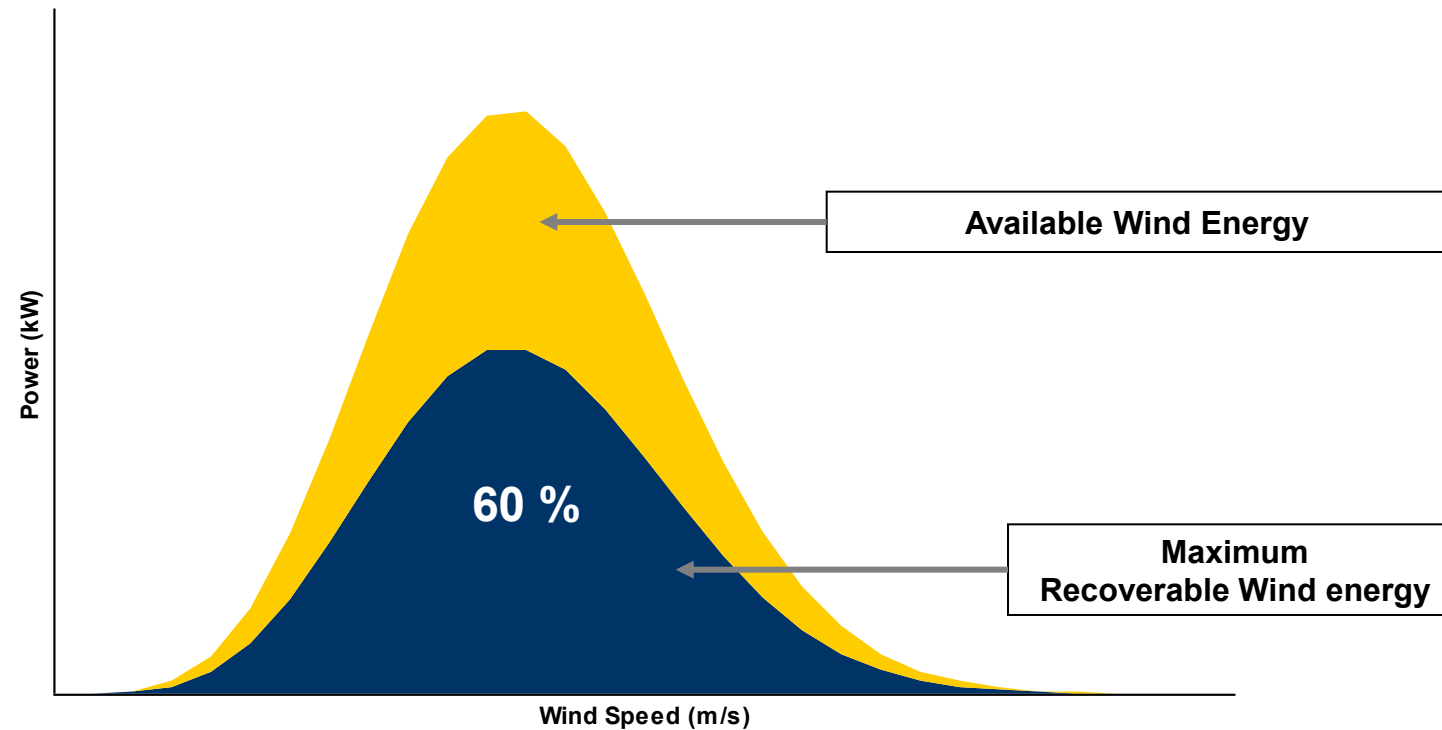


3 : result of 1 + 2

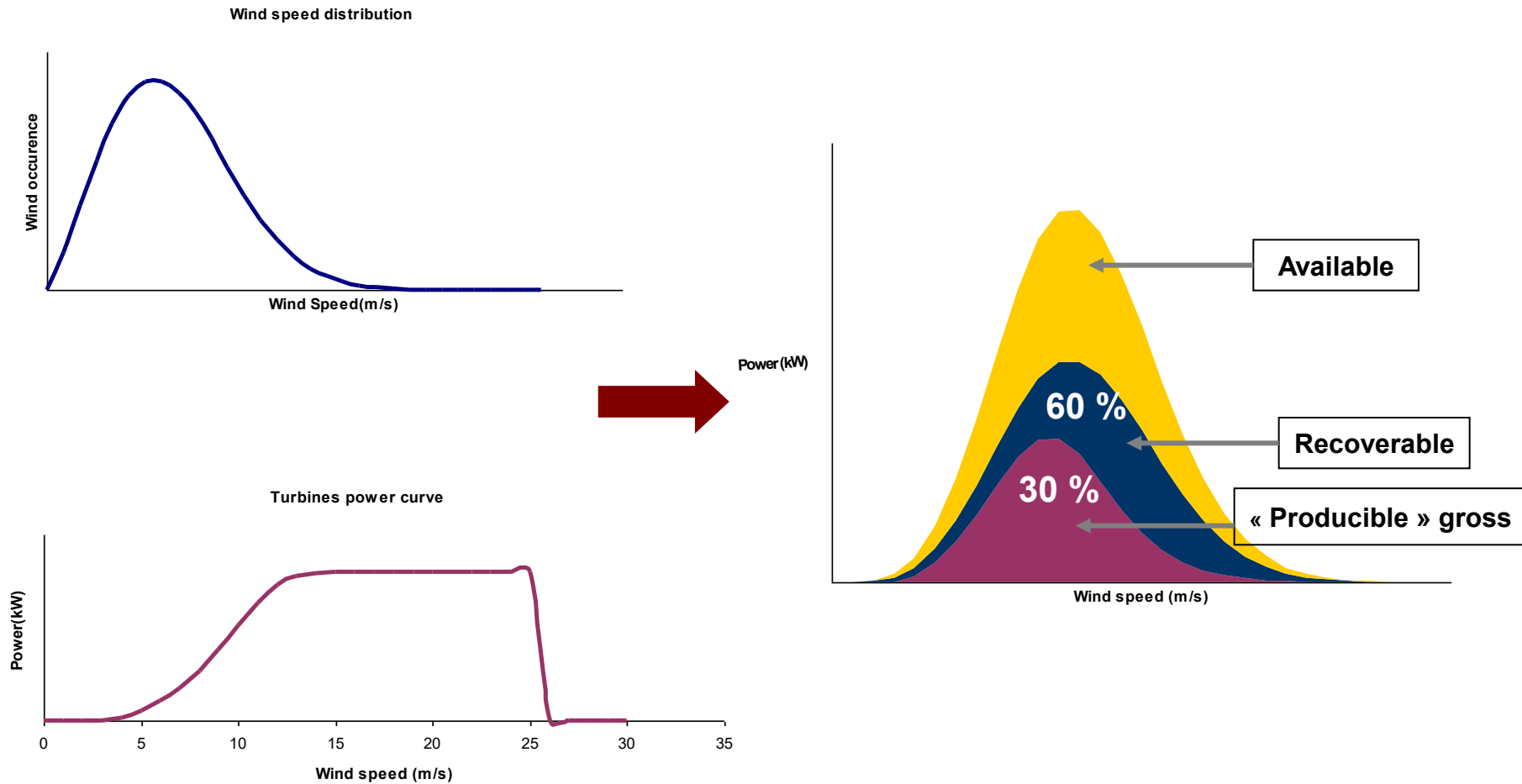


Theoretical maximum recoverable energy

Recoverable share of Wind energy is limited to # 60 % (Betz Law)



Gross production



Losses

◆ Additionnal losses in « real life »:

- Turbines technical non availability (3-5 %)
- Electric losses (1-4 %)
- Losses due to effect (3-5 %)
- Topographical losses and others (5 to 15%)

Total additionnal losses: 15 to 30%



Electricity Production versus installed Power

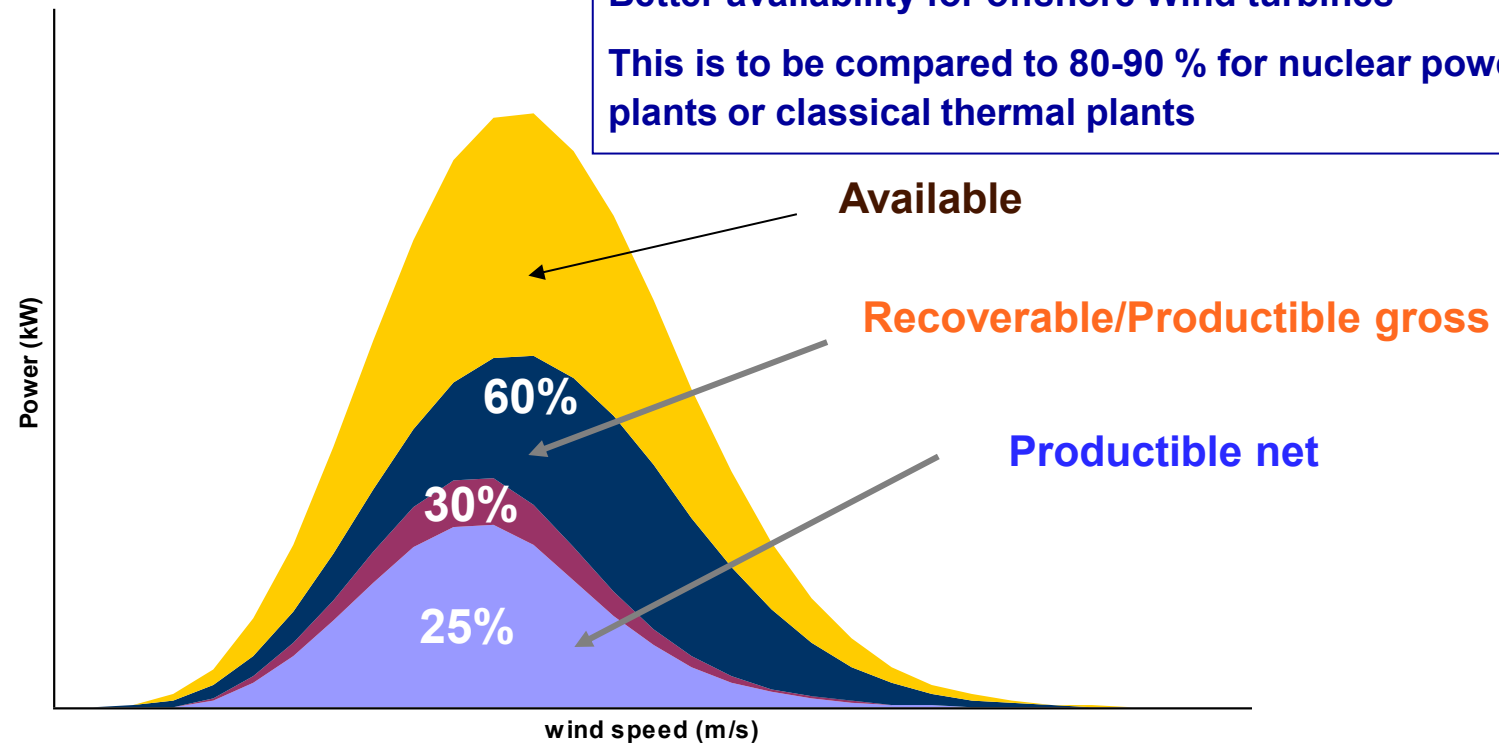
REAL LIFE EXPERIENCE:

25 % achieved only at early equipment stage

20 % is an average real availability

Better availability for offshore Wind turbines

This is to be compared to 80-90 % for nuclear power plants or classical thermal plants



Net production $\approx$ 25 % of Wind Energy

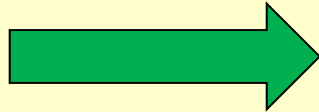


Output Power of a windmill

$$P_{\max} = 1/2 * 0,59 * \rho * Q * v^2$$

(Betz law limit)

$$Q = A * v$$



$$P_{\max} \# 0,30 * \rho * A * v^3$$

$P_{\max}$ = Maximum Output Power in kW

ρ = Air density (1,225 kg/m³)

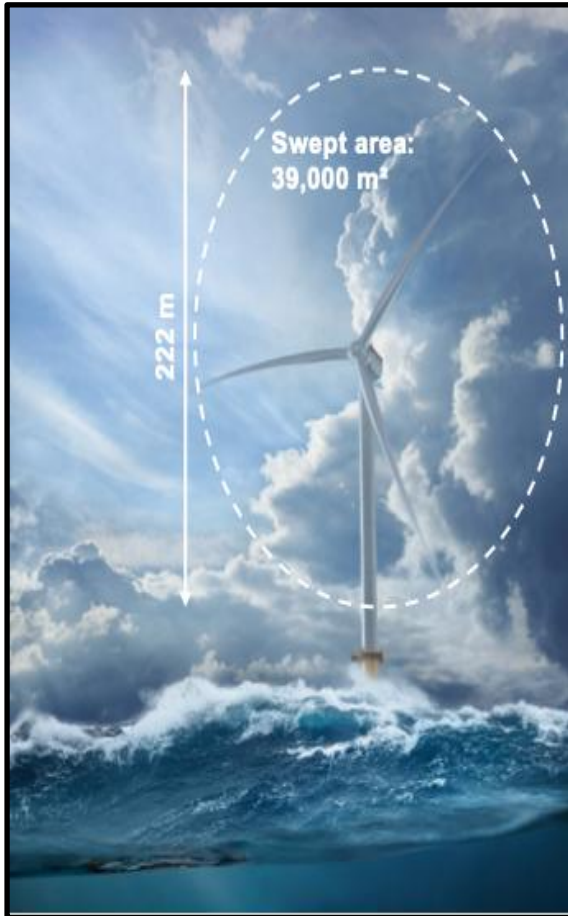
Q = Air flow (m³/s)

A = Swept area of the blades in m²

v = Wind velocity in m/s



14 MW Siemens Gamesa – Max power coefficient



SG 14-222 DD

IEC class	I, S
Nominal power	14 MW
Rotor diameter	222 m
Blade length	108 m
Swept area	39,000 m ²
Hub height	Site-specific
Power regulation	Pitch-regulated, variable speed

$$P_{\max} \# 0,30\rho A v^3$$

$$\rho = 1,225 \text{ kg/m}^3$$

$$A = 39,000 \text{ m}^2$$

$$V = 11 \text{ m/sec}$$

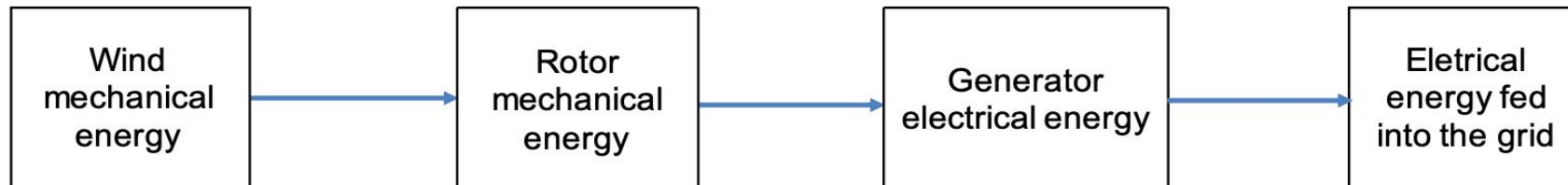
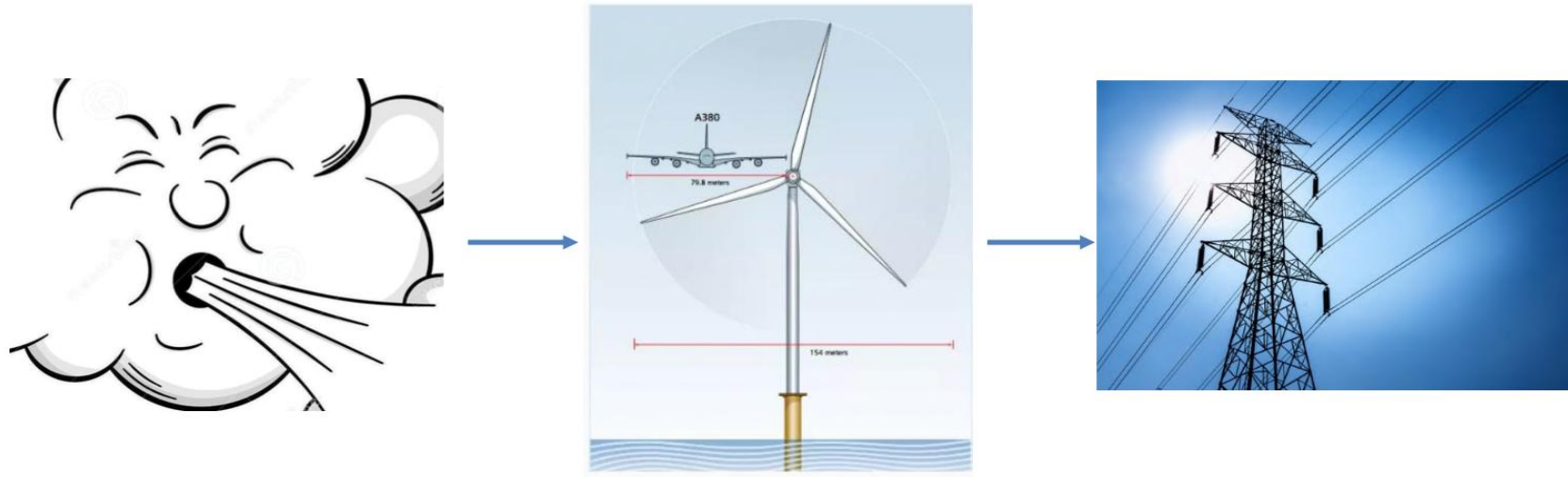
$$P_{\max} \# 19 \text{ MW}$$



Proof of the Betz Law



Energy conversion « from the wind to the electron »



- A wind turbine is a device designed to convert the energy of the wind into electricity
- From a minimum wind speed (~10 km/h) the wind energy drives the rotor of the wind turbine
- The rotational movement is transmitted to the horizontal axis which drives an electric generator
- The electrical energy is transported to the shore by cables and fed into the power grid

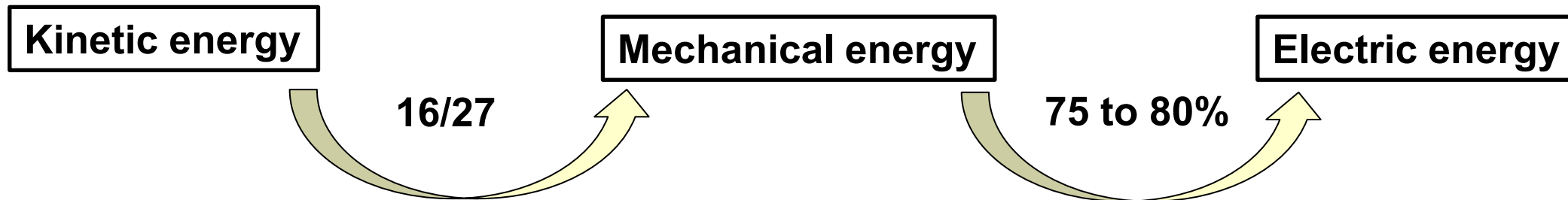


Betz Law

Betz law indicates the maximum power (i.e. the **mechanical energy**) that can be extracted from the wind, independent of the design of a wind turbine in open flow.

No turbine can capture more than $16/27$ of the **kinetic energy** in wind.

Utility-scale wind turbines usually achieve at peak 75 to 80% of the Betz limit as **electric energy**.



Betz Law - Kinetic Energy

v : Speed of the air flow

ρ : air density (supposed constant)

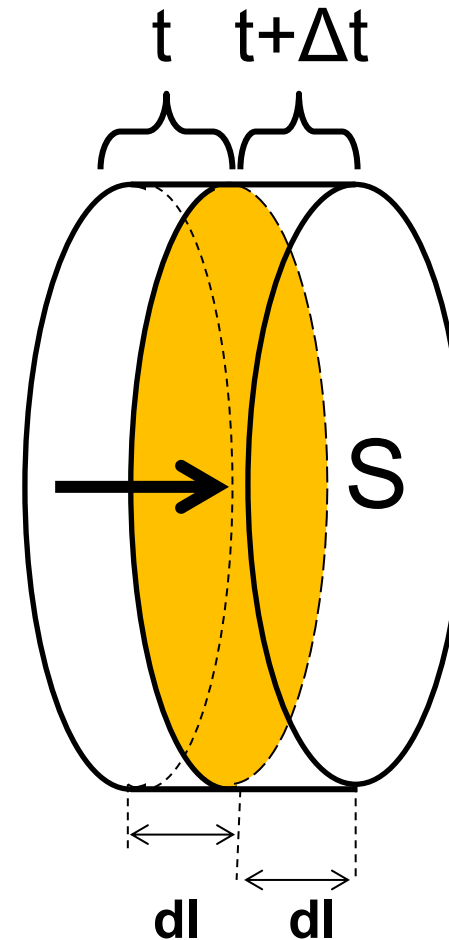
Kinetic Energy of a mass m of an elementary cylinder (length dl , area S) streaming through area S during Δt :

$$\Delta E_k = \frac{1}{2}mv^2 = \frac{1}{2}\rho S dl v^2$$

$$dl = v\Delta t \quad \longrightarrow \quad \Delta E_k = \frac{1}{2}\rho S v^3 \Delta t$$

$$\text{Kinetic Power} = P_k = \Delta E_k / \Delta t$$

$$P_k = \frac{1}{2}\rho S v^3$$



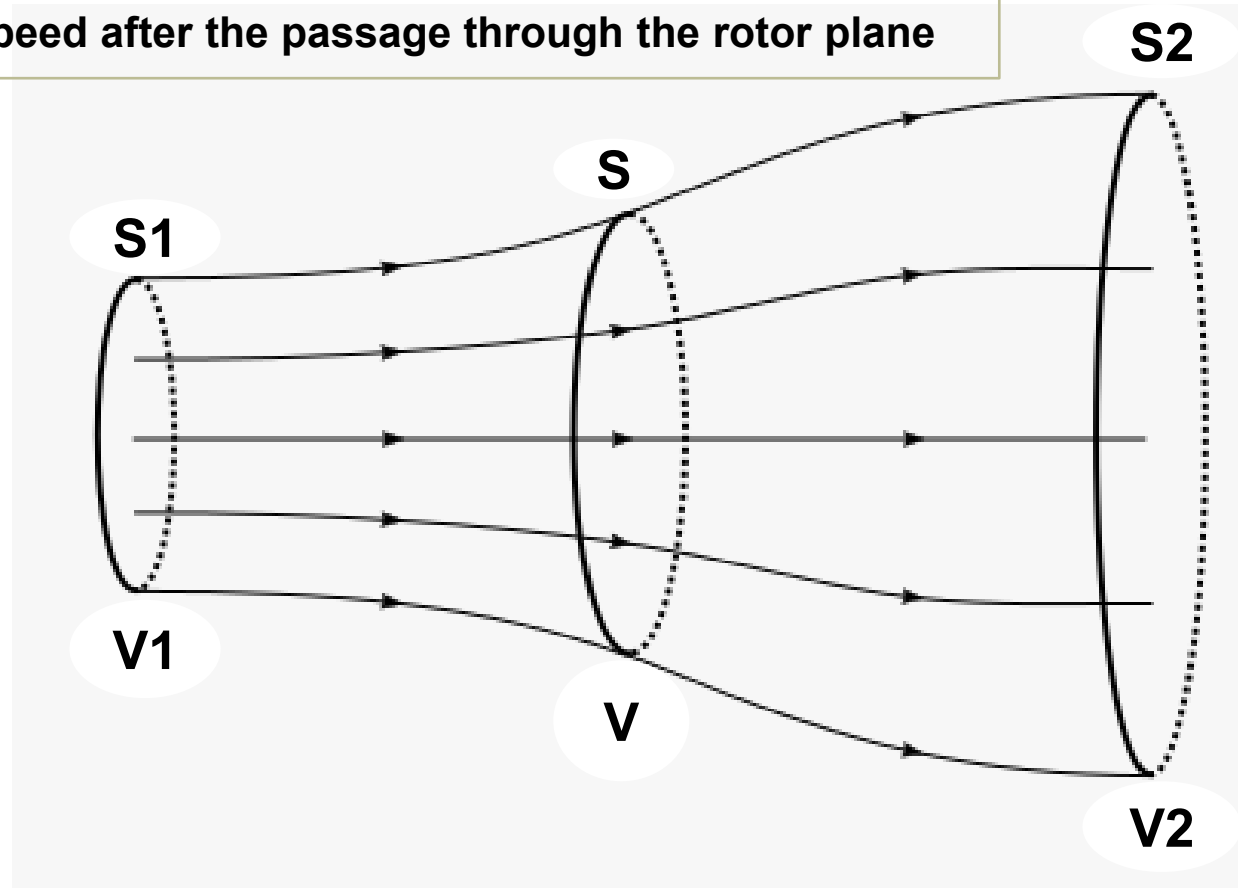
Betz Law

Air stream tube schematic

V1: Wind speed before the wind turbine

V : Wind speed at the level of the rotor

V2: Wind speed after the passage through the rotor plane



Betz law

Let's consider the stream tube.

Q: mass flow.

Mass flow is constant in the air stream tube.

Mass of air entering the stream tube equals the mass of air going out from the stream tube during Δt (Conservation of mass)

$$Q = m/\Delta t \quad Q = \rho S v \Delta t / \Delta t = \rho S v = Cst$$

That means $S_1 v_1 = S v = S_2 v_2$ ($v_1 > v > v_2$)

Power lost in the air stream tube:

$$P_w = P_1 - P_2 = 1/2 \rho (S_1 v_1^3 - S_2 v_2^3) = 1/2 \rho S_1 v_1 (v_1^2 - v_2^2)$$

$$P_w = 1/2 \rho S v (v_1^2 - v_2^2)$$



Betz law

The wind exerts a force on the wind turbine which receives a work transformed into a rotational mechanical energy.

$$W_t = Fdl = Fv\Delta t$$

The wind turbine receives a mechanical power P_t :

$$P_t = W_t/\Delta t \quad P_t = Fv$$

The force equals the variation of momentum:

$$p = mv$$

$$F = \Delta p/\Delta t = \Delta mv/\Delta t = m\Delta v/\Delta t = \rho Sdl \Delta v/\Delta t$$

$$F = \rho Sv(v_1 - v_2)$$

$$P_t = \rho Sv^2(v_1 - v_2)$$

The power received by the wind turbine equals power lost in the air stream tube:

$$P_w = P_t \quad 1/2\rho Sv(v_1^2 - v_2^2) = \rho Sv^2(v_1 - v_2)$$

$$\text{Therefore, } v = 1/2 (v_1 + v_2)$$

$$\text{And } P_t = 1/4\rho S(v_1 + v_2)^2(v_1 - v_2)$$



Betz law

Let's define the Coefficient of Performance (ratio between the power gained by the wind turbine and the power of the upstream air flow):

$$C_p = P_t / P_1$$

$$P_t = 1/4 \rho S (v_1 + v_2)^2 (v_1 - v_2)$$

$$P_1 = 1/2 \rho S v_1^3$$

$$C_p = 1/2 (v_1 + v_2)^2 (v_1 - v_2) / v_1^3$$

Let's define $x = v_2 / v_1$

$$C_p(x) = 1/2 (1 + x)^2 (1 - x)$$

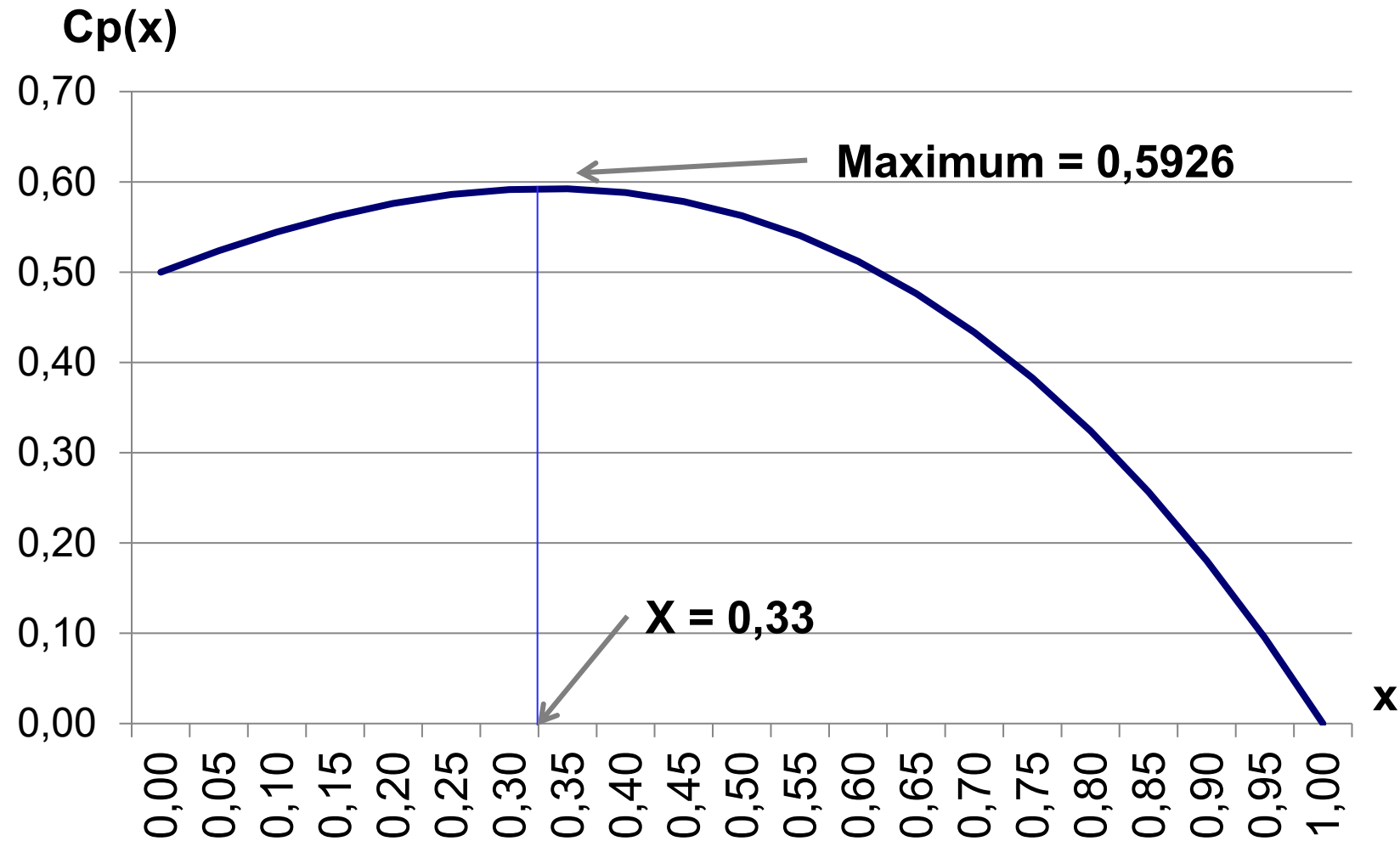
$$dC_p/dx = 1/2 (-3x^2 - 2x + 1) \quad dC_p/dx = 0 \text{ for } x = 1/3$$

$$C_{p \text{ max}} = 16/27 = 0,5926$$

$$P_{t \text{ max}} = 1/2 * 0,5926 \rho S v_1^3 \approx 0,30 \rho S v_1^3$$



Betz law – Max power coefficient



2-2

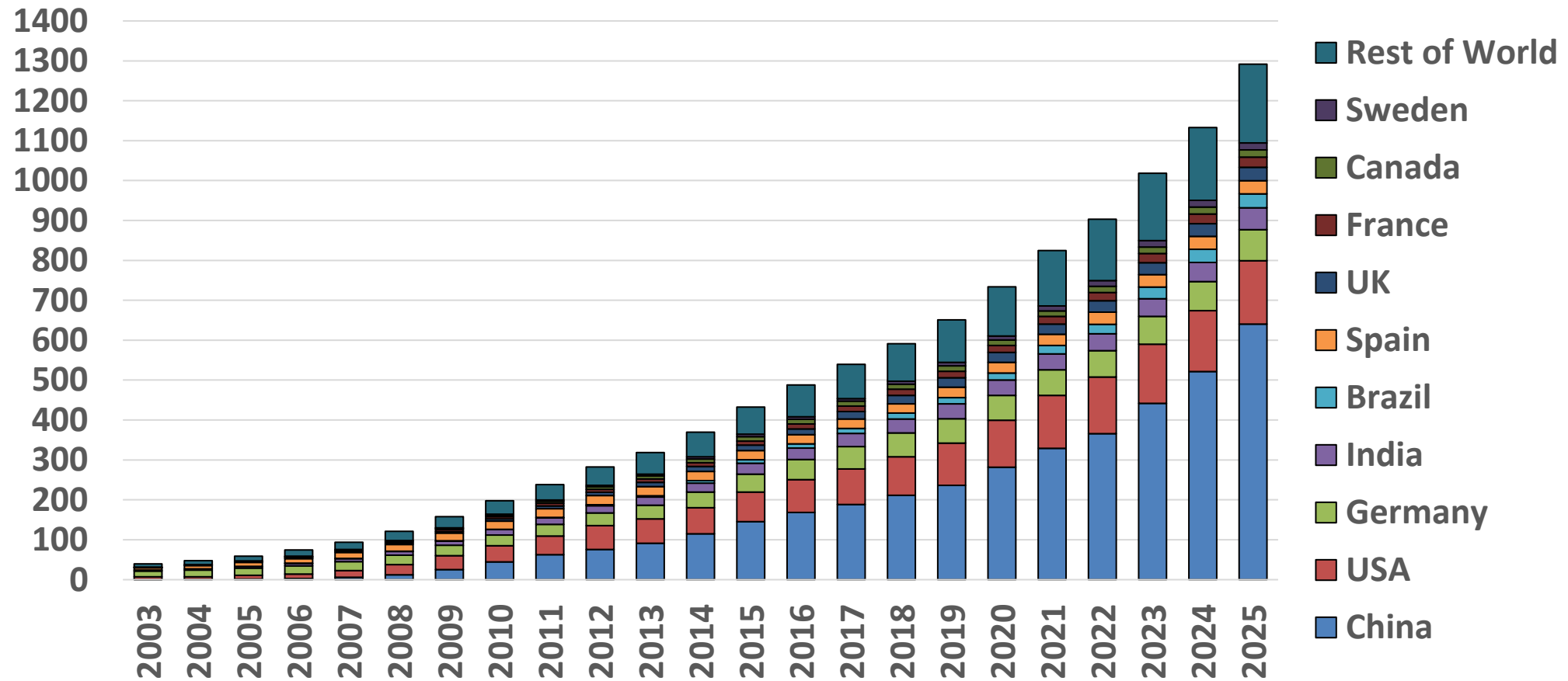
Wind Energy Markets



Evolution of Installed Wind Power Capacity (GW)

N°1 China, N° 2 US

Total 2025: # 1290 GW out of which 79 GW offshore (7,1%)



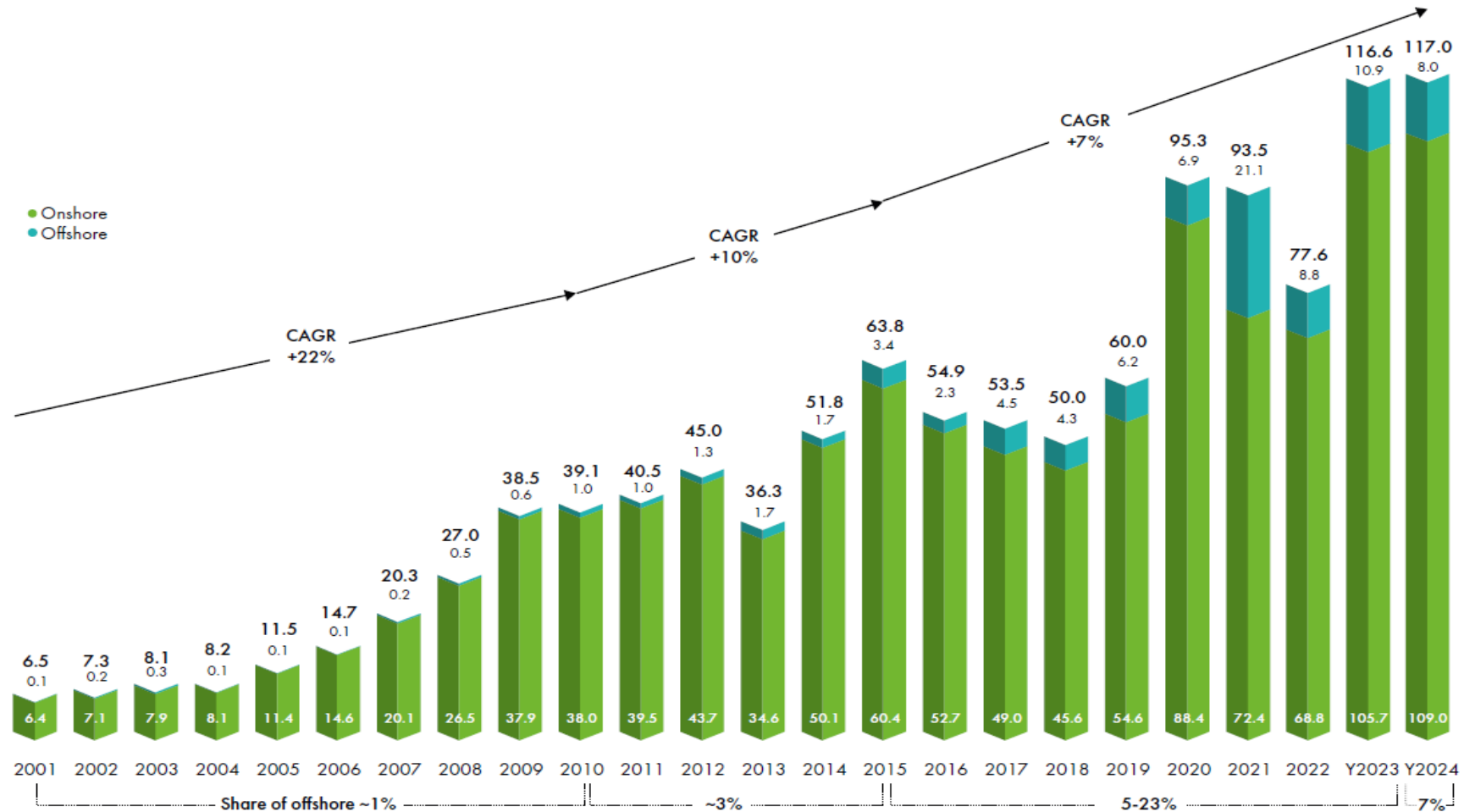
Source: Data from IRENA 2026

Figures represent the maximum net generating capacities installed and connected at the end of the year



New Wind Installations History 2001-2024 (GW)

Historic development of new installations (GW)



Footnote: GWEC made the adjustments to new installations and total installation in 2023 based on the updated statistics GWEC received. For details see Appendix -Methodology and Terminology

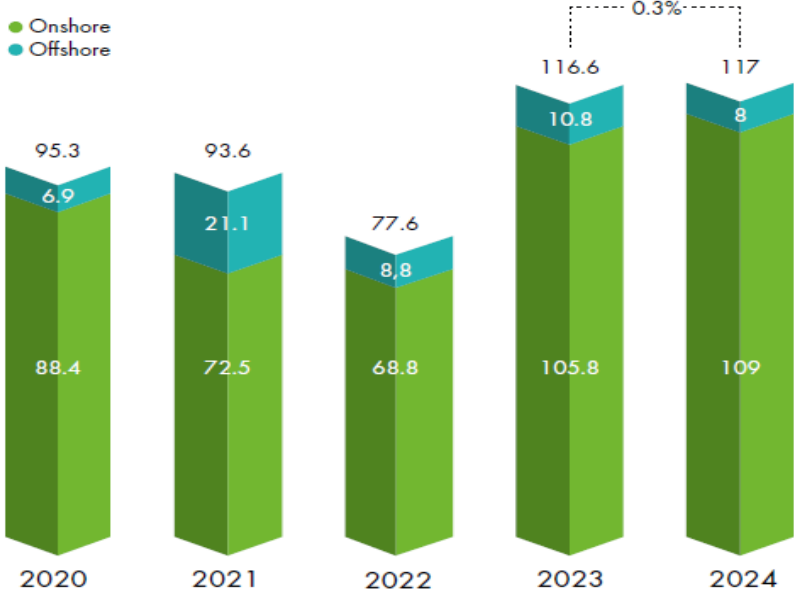
Source: GWEC Global Wind report 2025



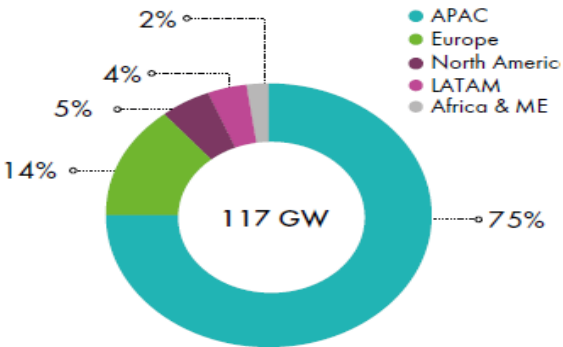
New Wind Installations Outlook 2020-2024 (GW)

New installations
GW

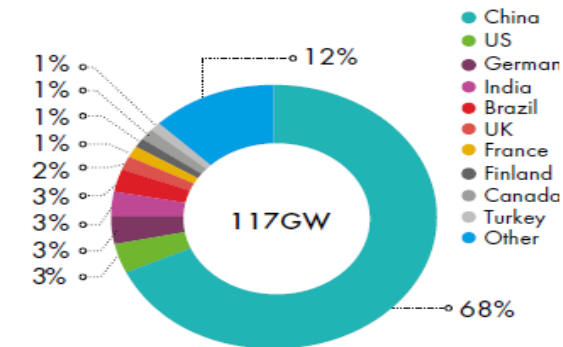
● Onshore
● Offshore



New capacity in 2024 installed by
region (%)



New capacity 2024 and share of top
10 markets (%)

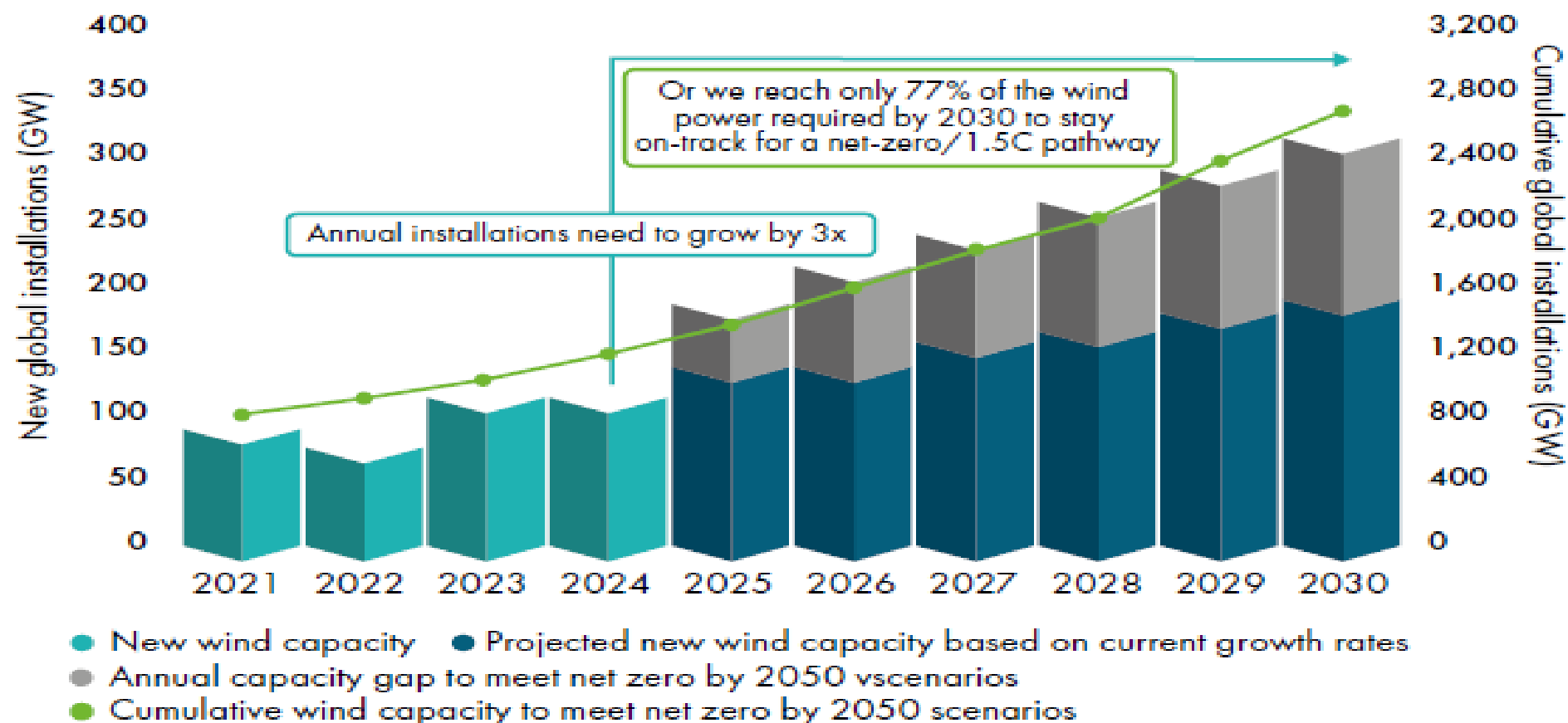


Source: GWEC Global Wind report 2025

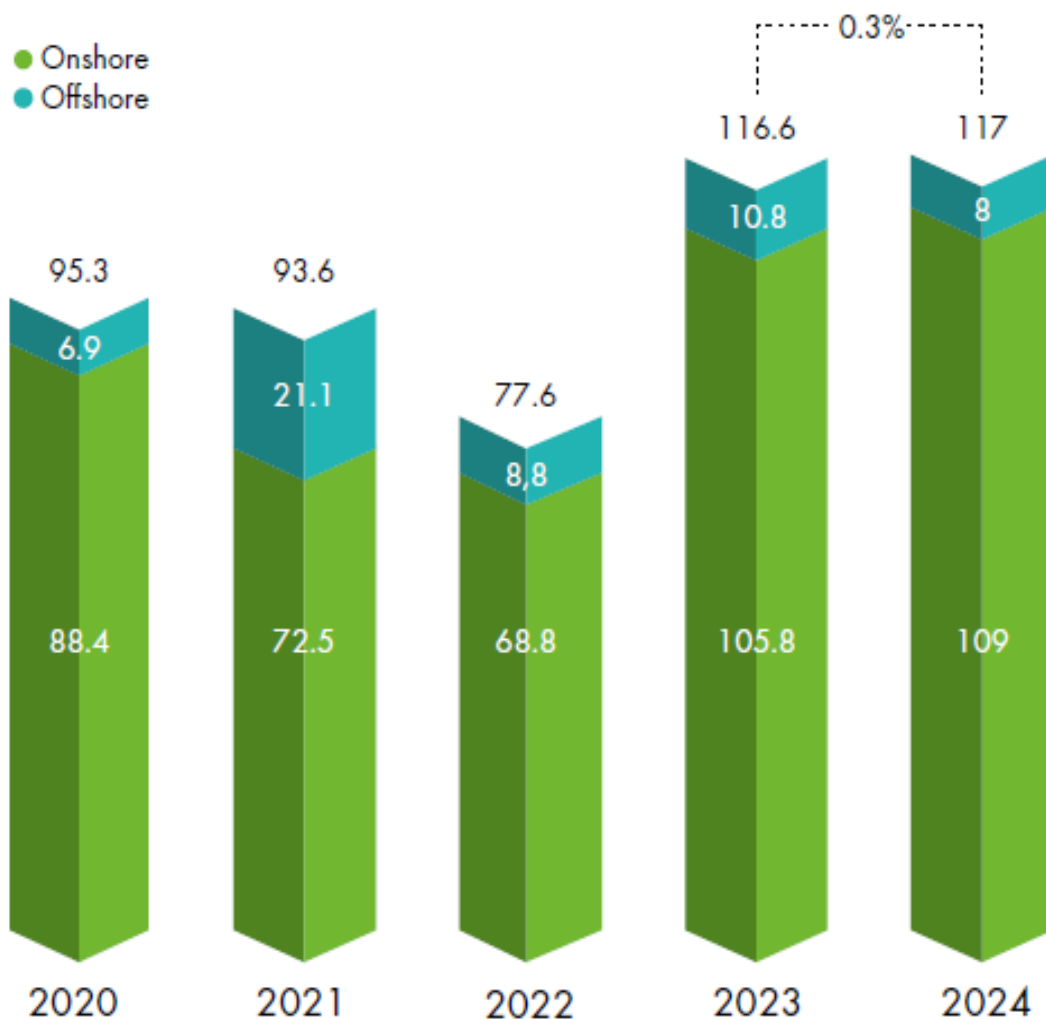


New Wind Installations Outlook 2021-2030 (GW)

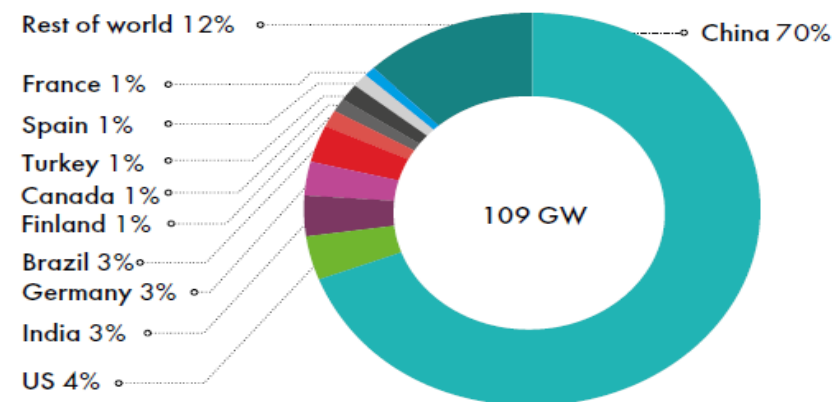
Wind power installations need to triple by 2030 in order to achieve a 1.5°C Pathway



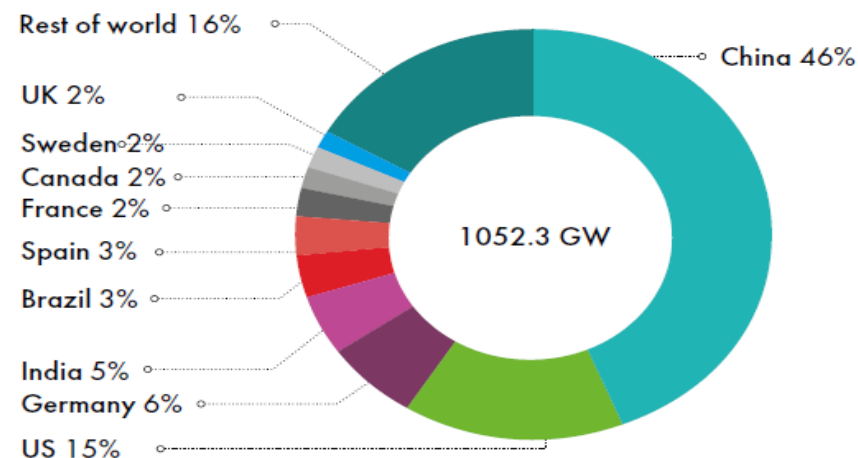
New Onshore Wind Installations by country 2020-2024 (GW)



New installations onshore (%)



Total installations onshore (%)

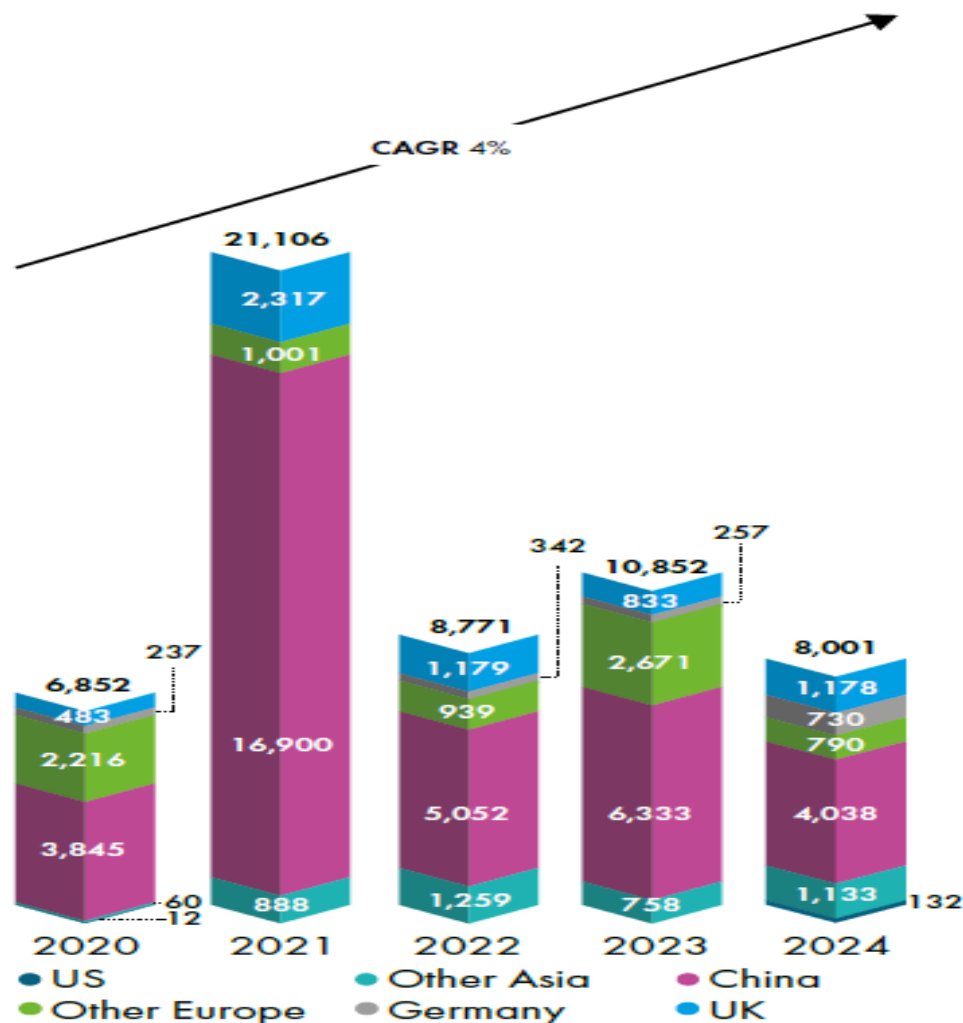


Source: GWEC Global Wind report 2025



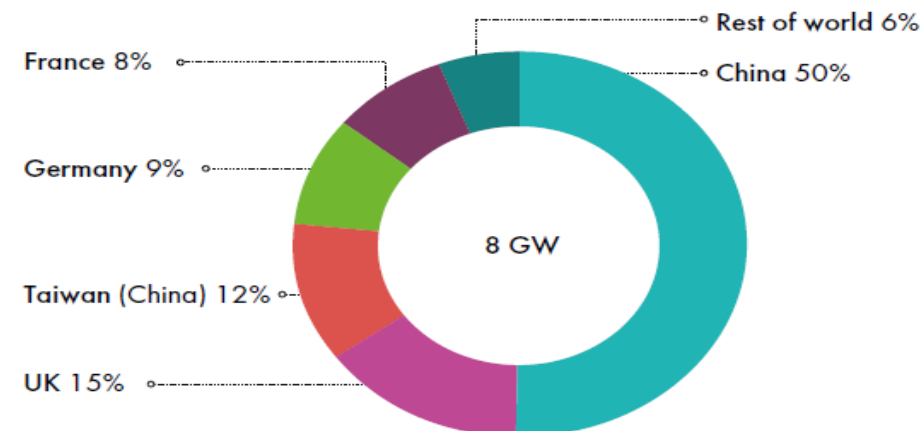
New Offshore Wind Installations by country 2020-2024 (GW)

New offshore installations (MW)

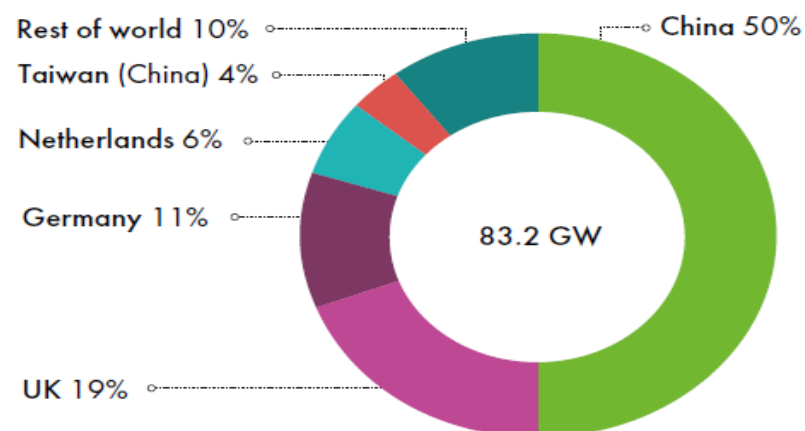


Source: GWEC Global Wind report 2025

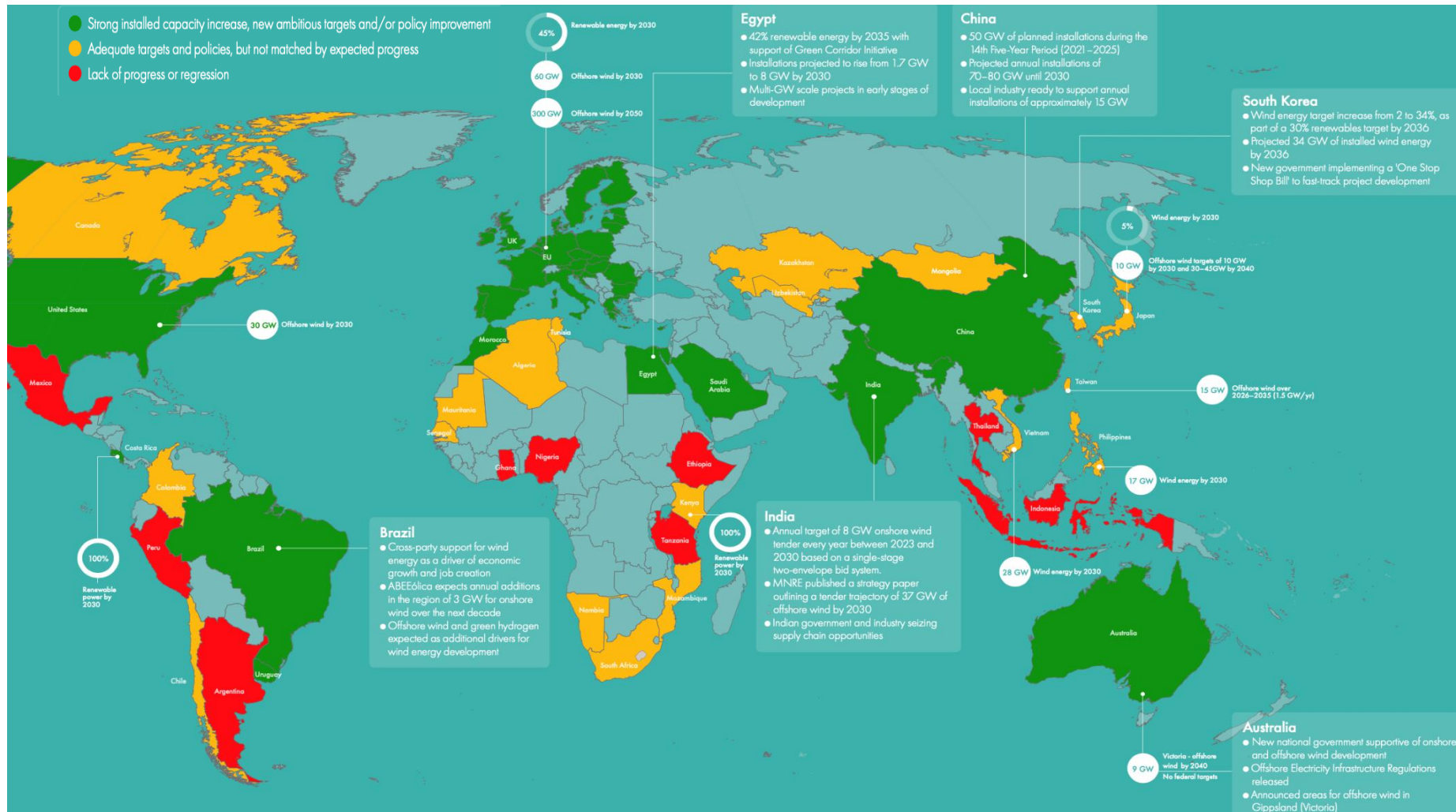
New installations offshore (%)



Total installations offshore (%)



Offshore Wind Annual Installed Capacity Forecast 2030-2050



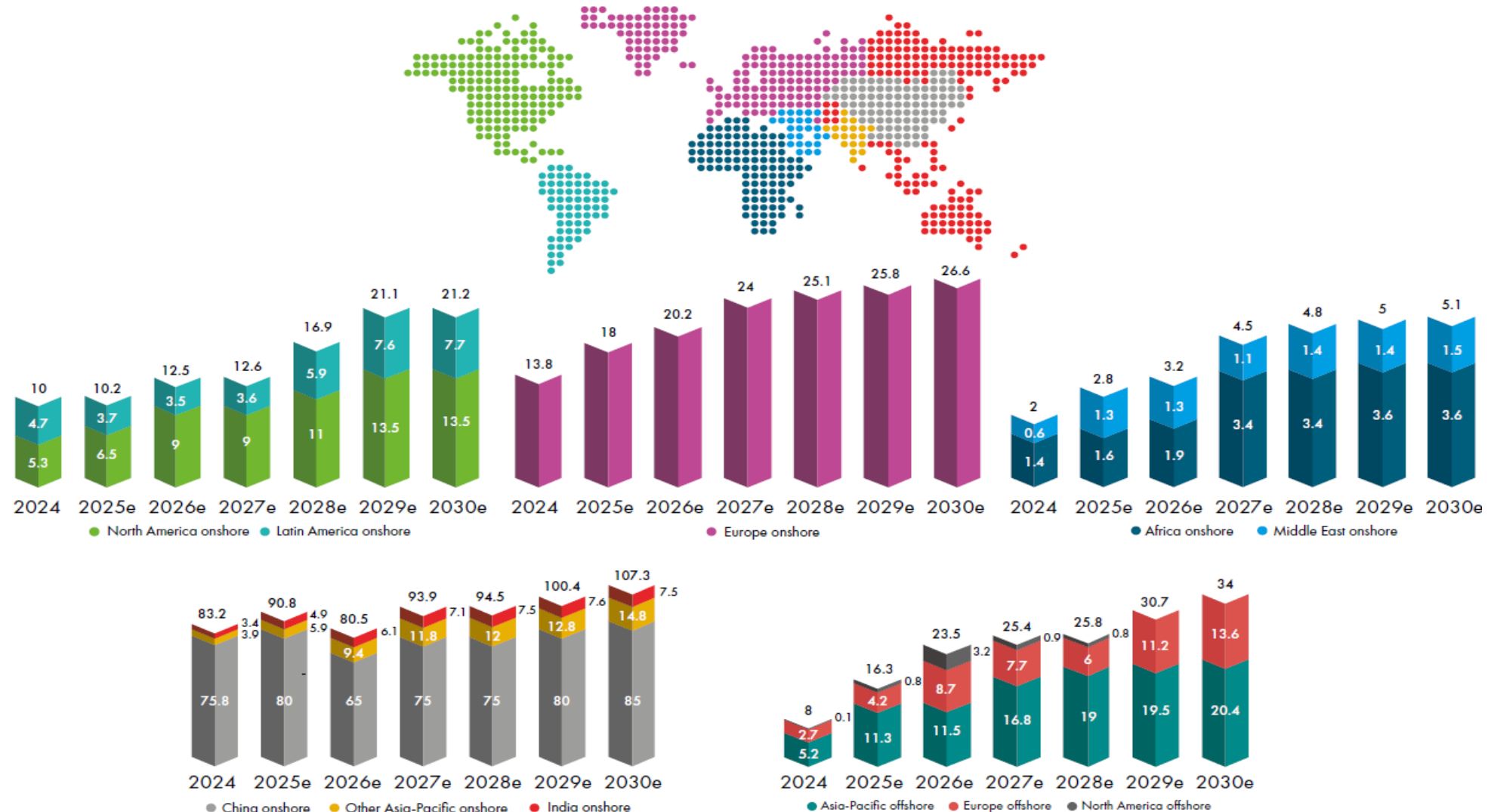
2022 64 GW
2030 430 GW
2050 2,000 GW

The global offshore wind sector expects to grow rapidly and account for circa 20% share of the total wind capacity installed in 2030.



Global Wind Annual Outlook for new Capacities 2024 - 2030

Regional onshore and offshore wind outlook for new installations (GW)



Source: GWEC Global Wind report 2025

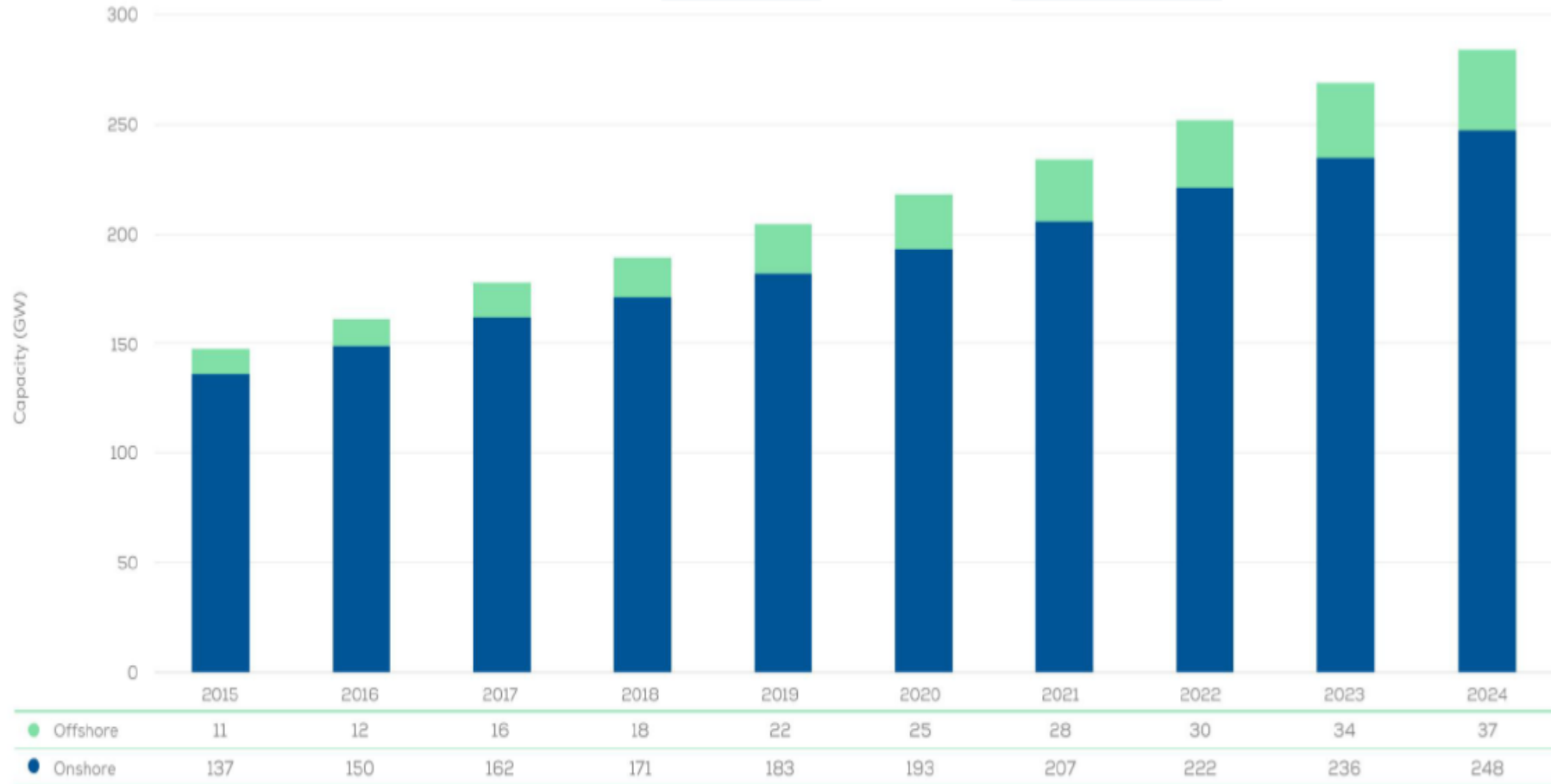


A Zoom on Europe



Installed Wind Power Capacity in Europe (GW)

At the end of 2023, Europe has 285 GW of installed wind energy capacity. 87% (210 GW) of this is built onshore with the remaining 13% (37 GW) built offshore.

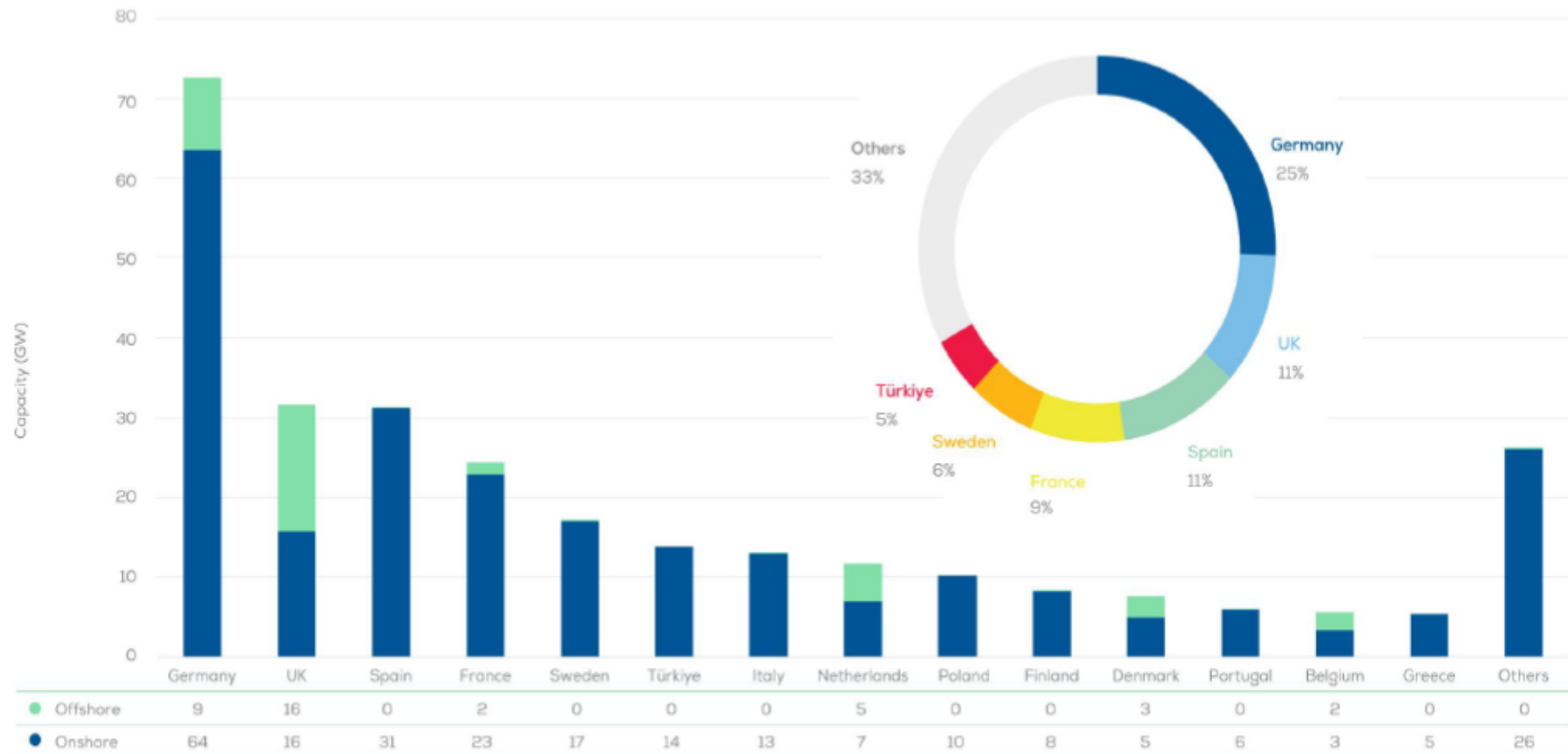


Source: WindEurope



Installed Wind Power Capacity in Europe (GW)

More than 50% of Europe's installed wind energy capacity is built in just four countries: Germany, UK, Spain, and France. Germany alone accounts for 25% of Europe's and 31% of the EU's installed wind energy capacity.

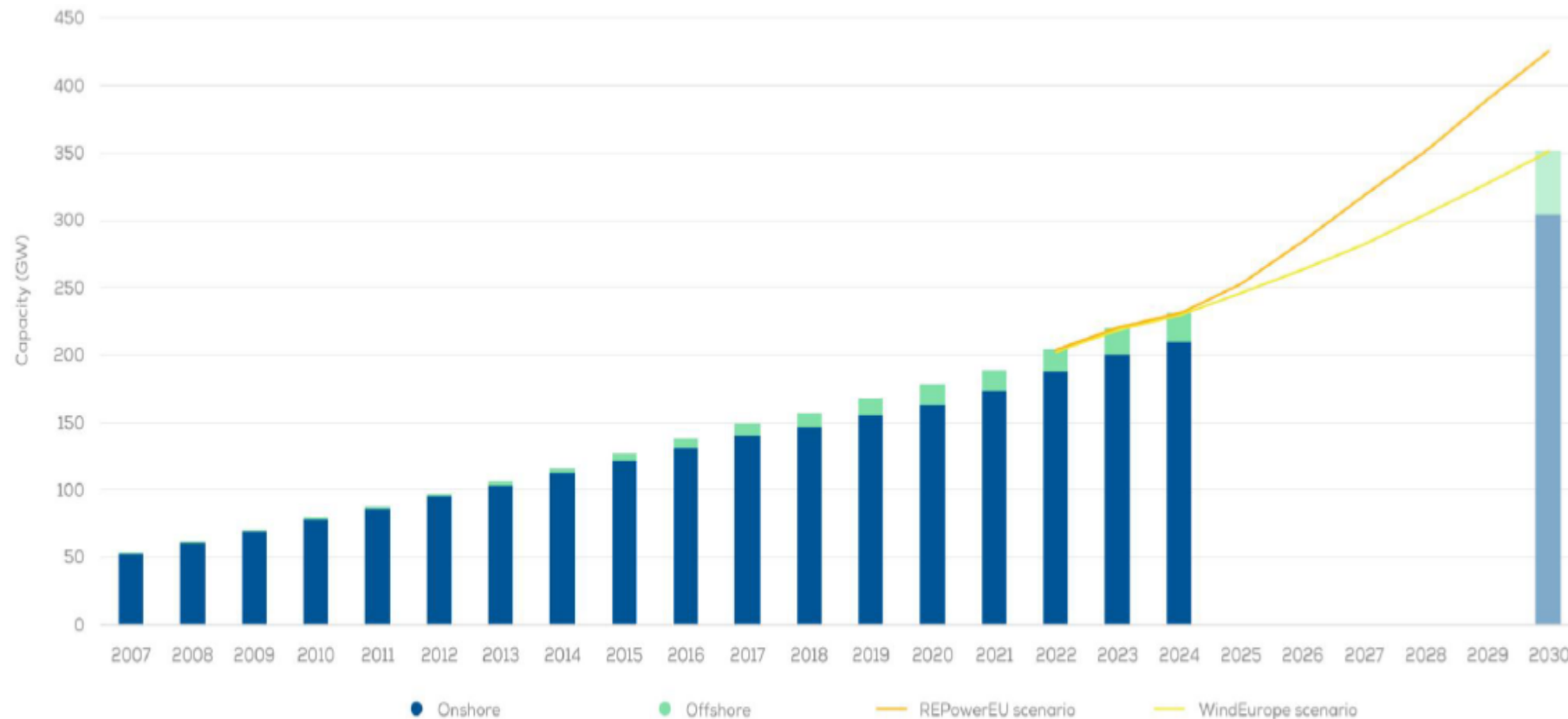


Source: WindEurope



Installed Wind Power Capacity in EU (GW) and projections

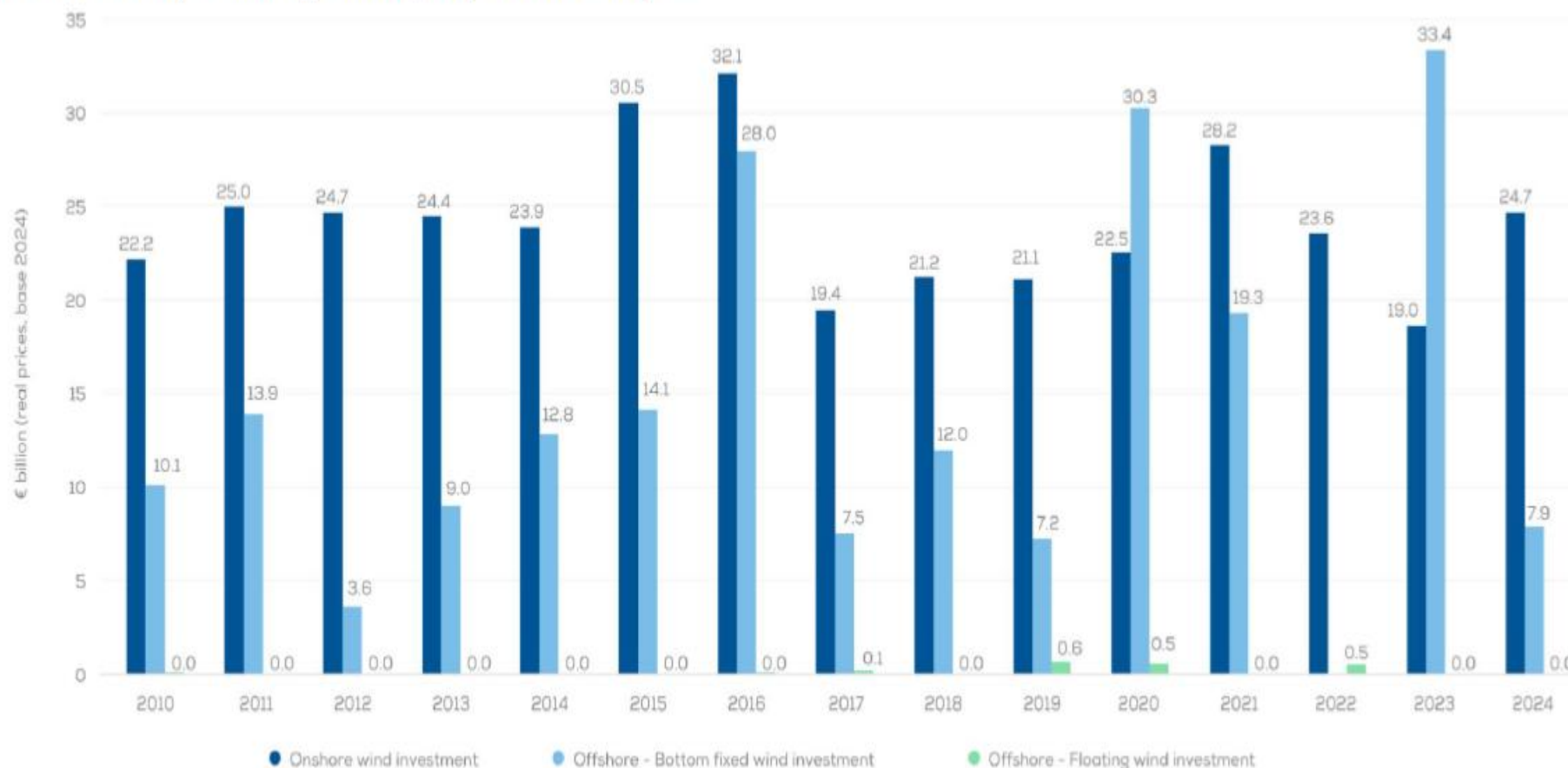
At the end of 2024, the EU has 231 GW of installed wind energy capacity. 91% (210 GW) of this is built onshore with the remaining 9% (21 GW) built offshore. According to the European Commission, the EU would need 425 GW of wind energy installed capacity by 2030 to meet its climate goals.



Source: Deloitte for ETIPWind

Investments in new Wind Farms in Europe (G€)

Wind Energy investments totaled €32.6bn of which 75% (€24.7bn) went to onshore wind. In total 19.9 GW of new capacity was financed. 17.3 GW of onshore wind and 2.6 GW of bottom-fixed offshore wind. There was no investment in any floating wind project in Europe.

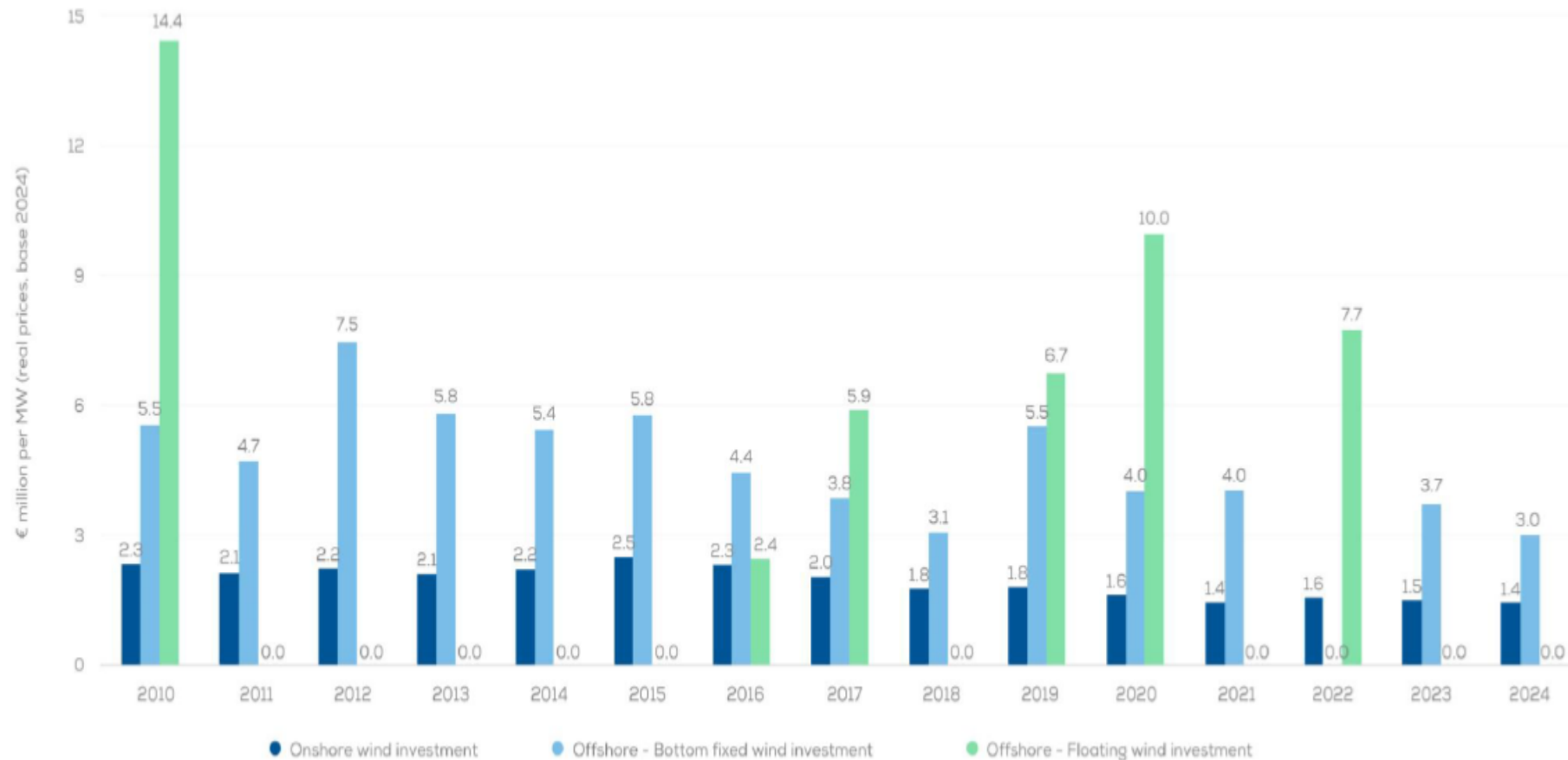


Source: Deloitte for ETIPWind



Investment Intensity of Wind Energy in Europe (€/MW)

The average investment cost for onshore wind remains stable at more or less €1.4m per MW. Average investments cost for new bottom-fixed offshore wind remain highly market-specific as can they entail different development costs, most notably the grid connection. There was no investment in new floating offshore wind.

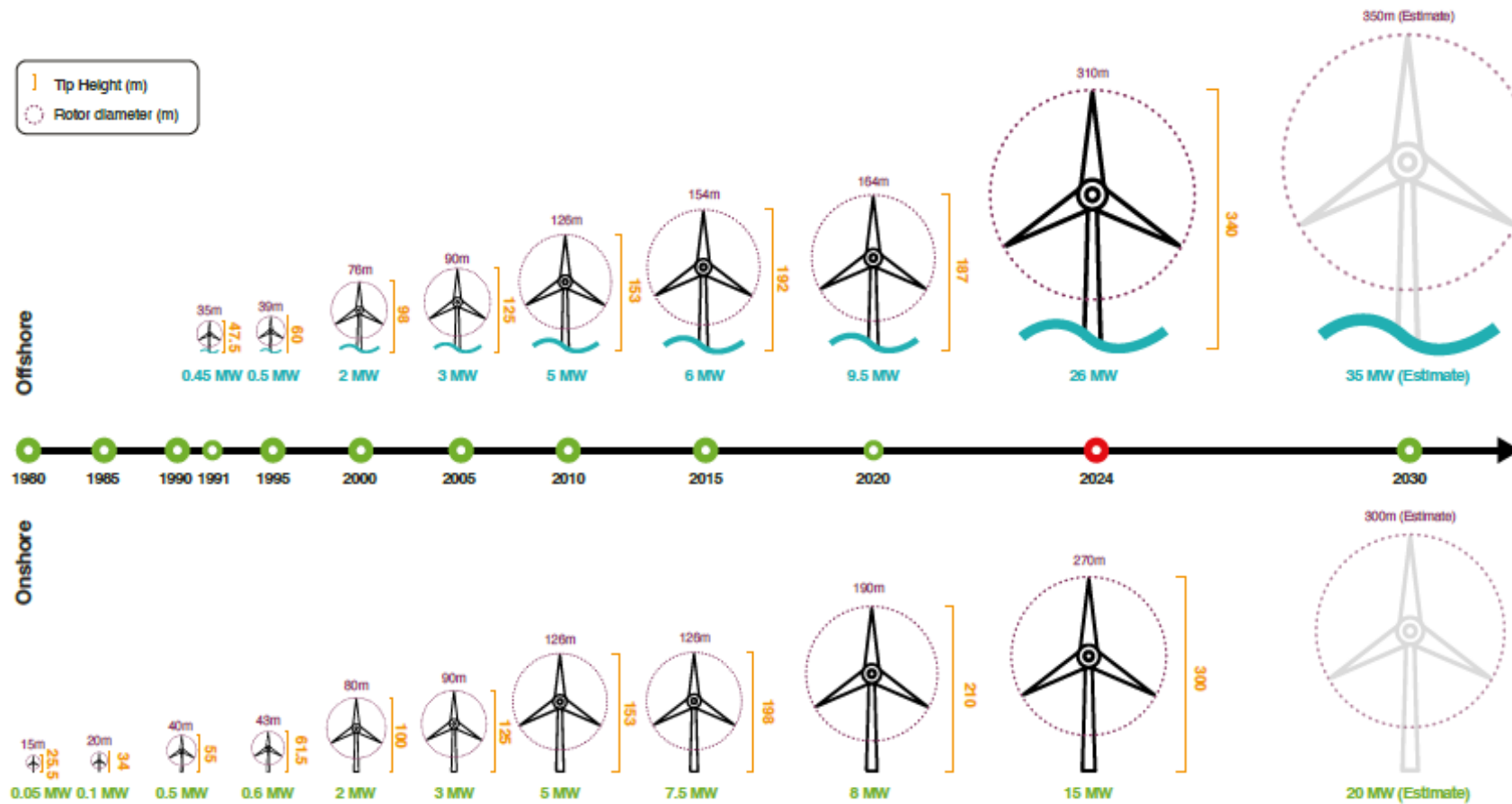


Source: Deloitte for ETIPWind



Wind Energy – Turbine size evolution

Trend of onshore and offshore turbine size, 1980-2030

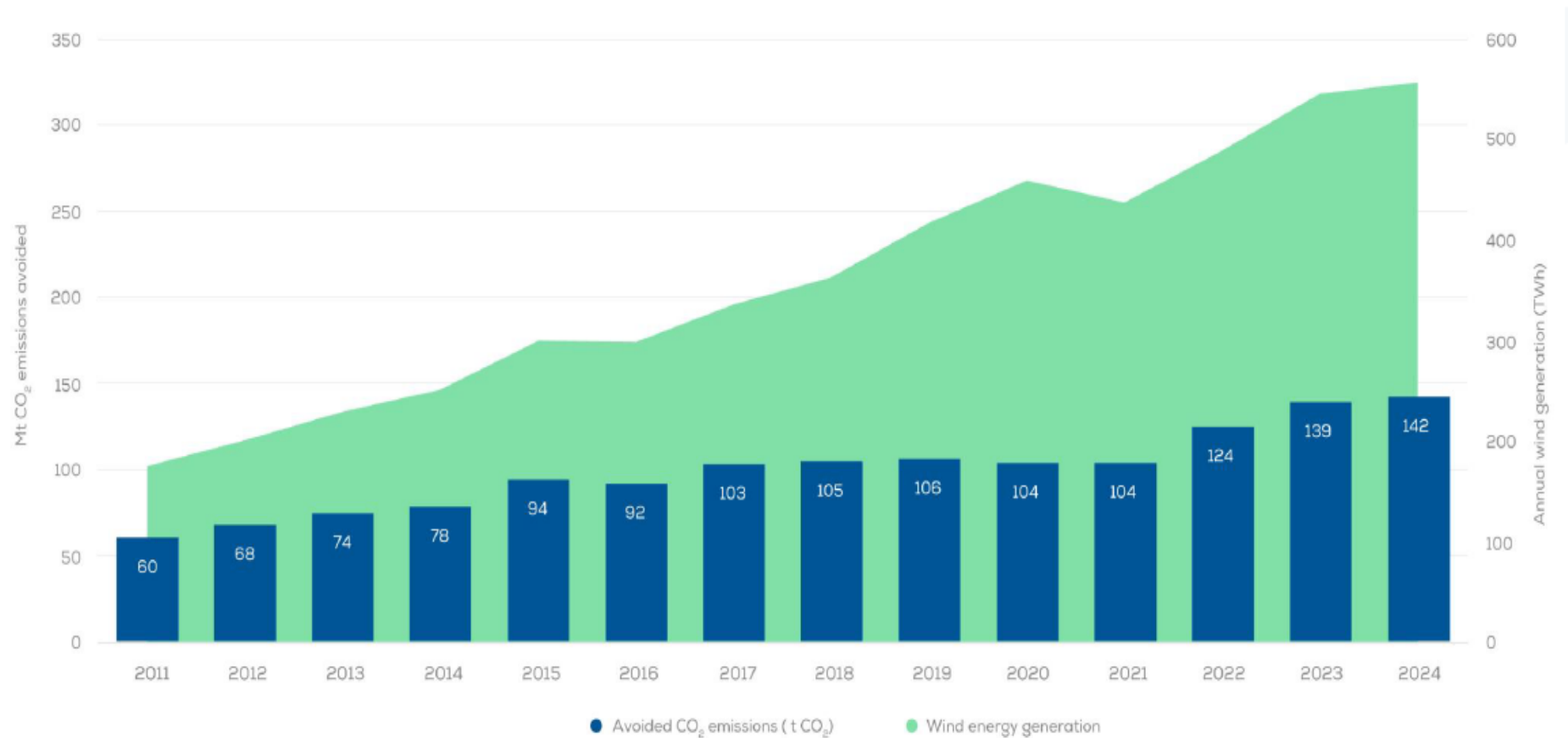


Source: GWEC Market Intelligence.



Avoided CO₂ Emissions

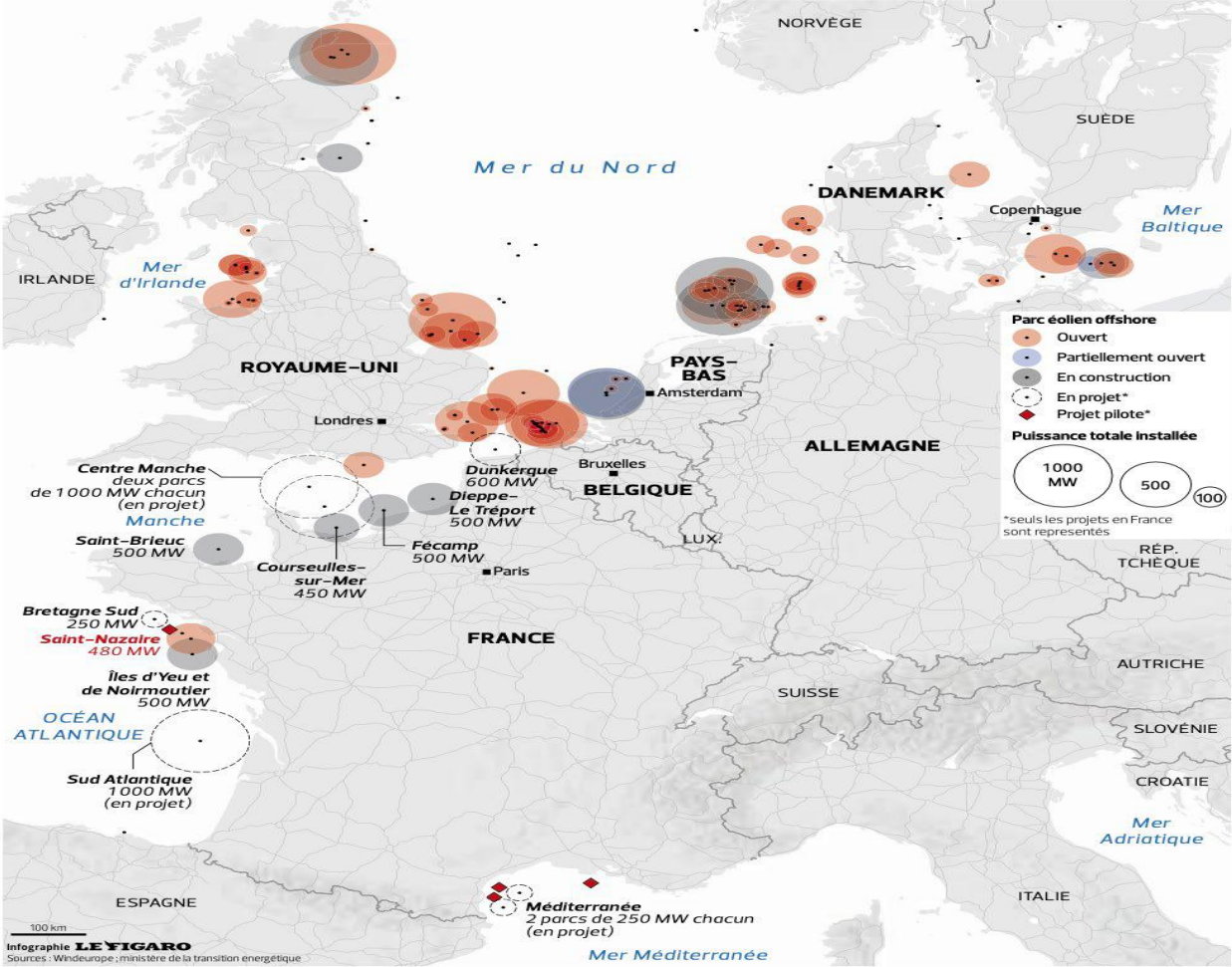
Wind energy generation avoided 142 million tons of CO₂ emissions in Europe. This amounts to economic sav of €8bn in Europe assuming the average carbon price of €56.6 per tonne of CO₂ emitted.



Source: ECB; World Bank, Deloitte for ETIPWind



Wind Offshore overview in Europe



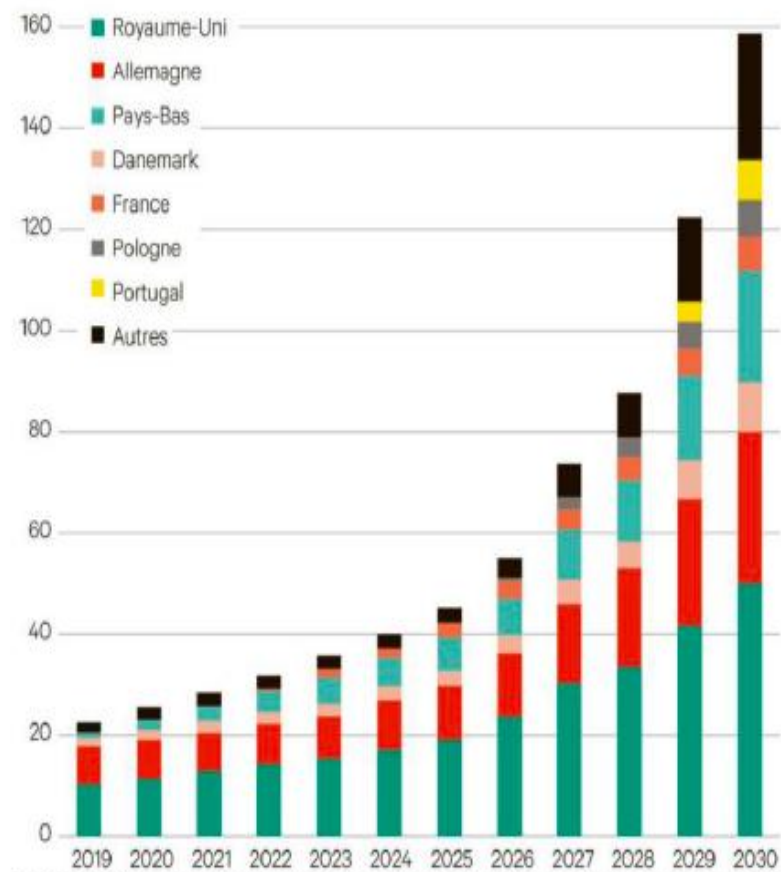
Source: Wind Europe, Ministère de la Transition Energétique, le Figaro



Wind Offshore overview in Europe

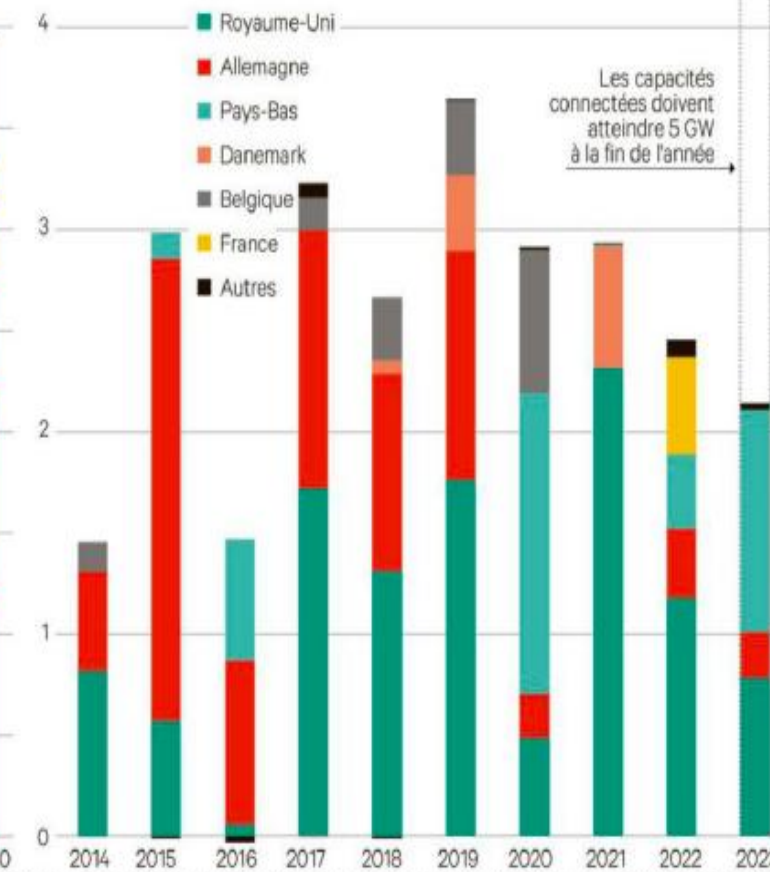
Les objectifs de déploiement de l'éolien en mer en Europe sont exponentiels...

Objectifs de déploiement de capacités cumulées en GW d'ici à 2030



...mais le nombre d'éoliennes en mer connectées aux réseaux risque de marquer le pas

Capacités d'éoliennes en mer connectées aux réseaux électriques, en GW



Les capacités connectées doivent atteindre 5 GW à la fin de l'année

• LES ÉCHOS • / SOURCE : WIND EUROPE



2-3

Offshore Wind Energy

A major advantage: wind speed and regularity: average 2500 hours/years versus 2000 onshore.

A major disadvantage: costs.

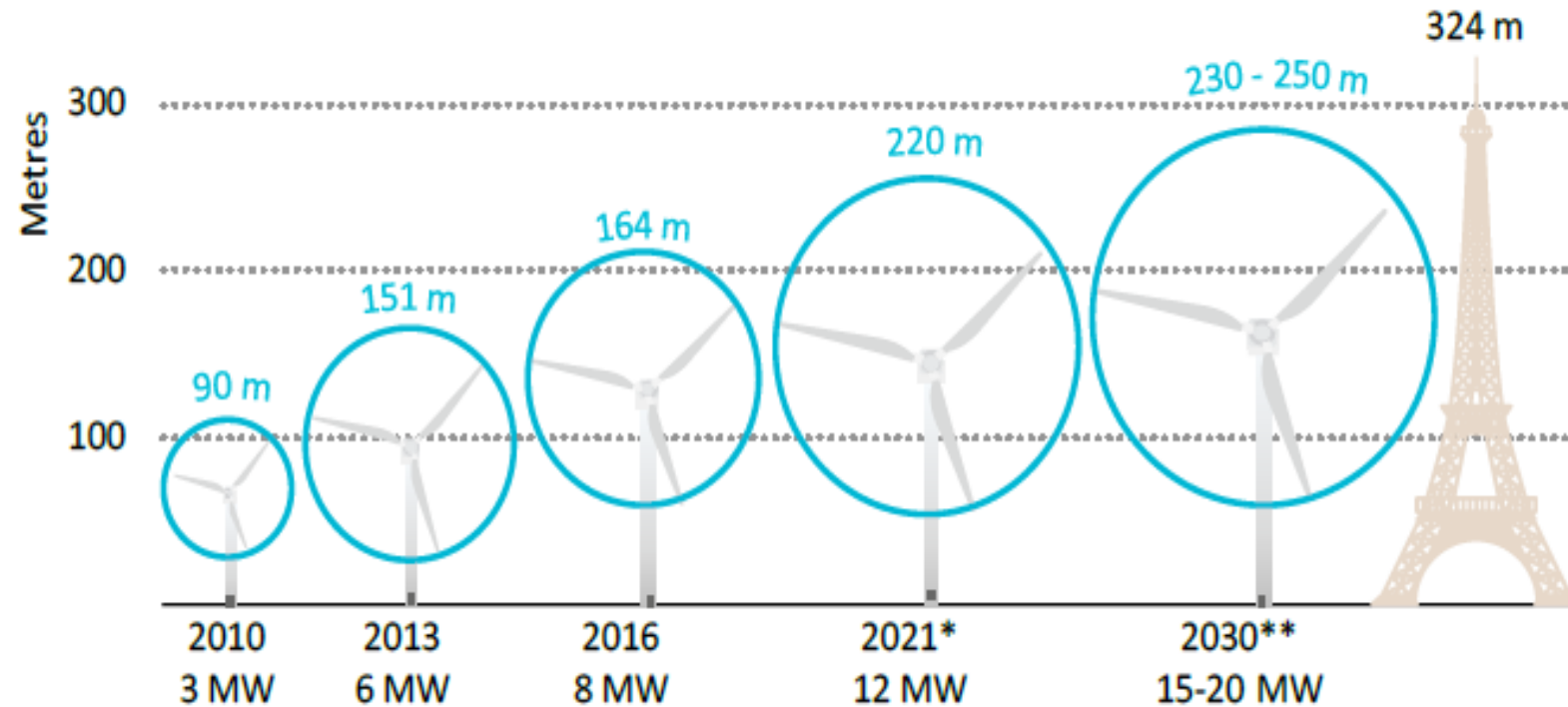


Offshore Wind Farms



Source: EWEA

Wind offshore: The Past and the Future – IEA vision 2019



Technology advances enabled offshore wind turbines to become much bigger in just a few years and are supporting ongoing increases in scale

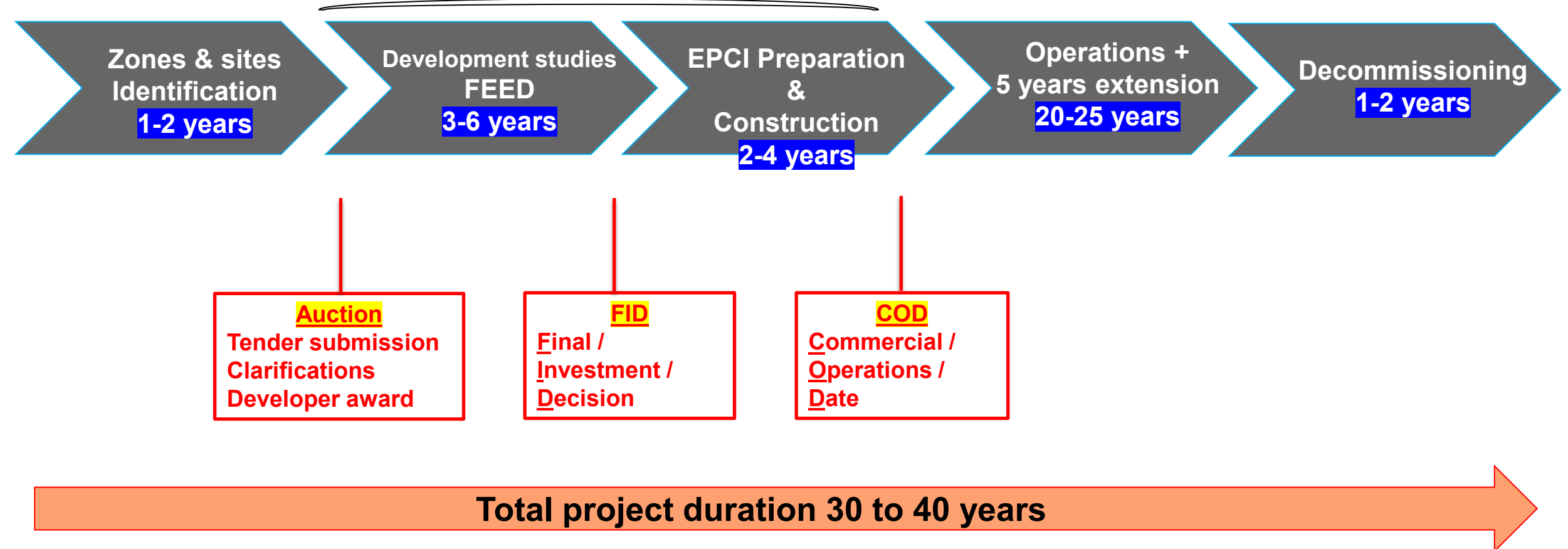
* Announced expected year of commercial deployments. ** Further technology improvements through to 2030 could see bigger turbines sizes of 15-20 MW.

Notes: Illustration is drawn to scale. Figures in blue indicate the diameter of the swept area.



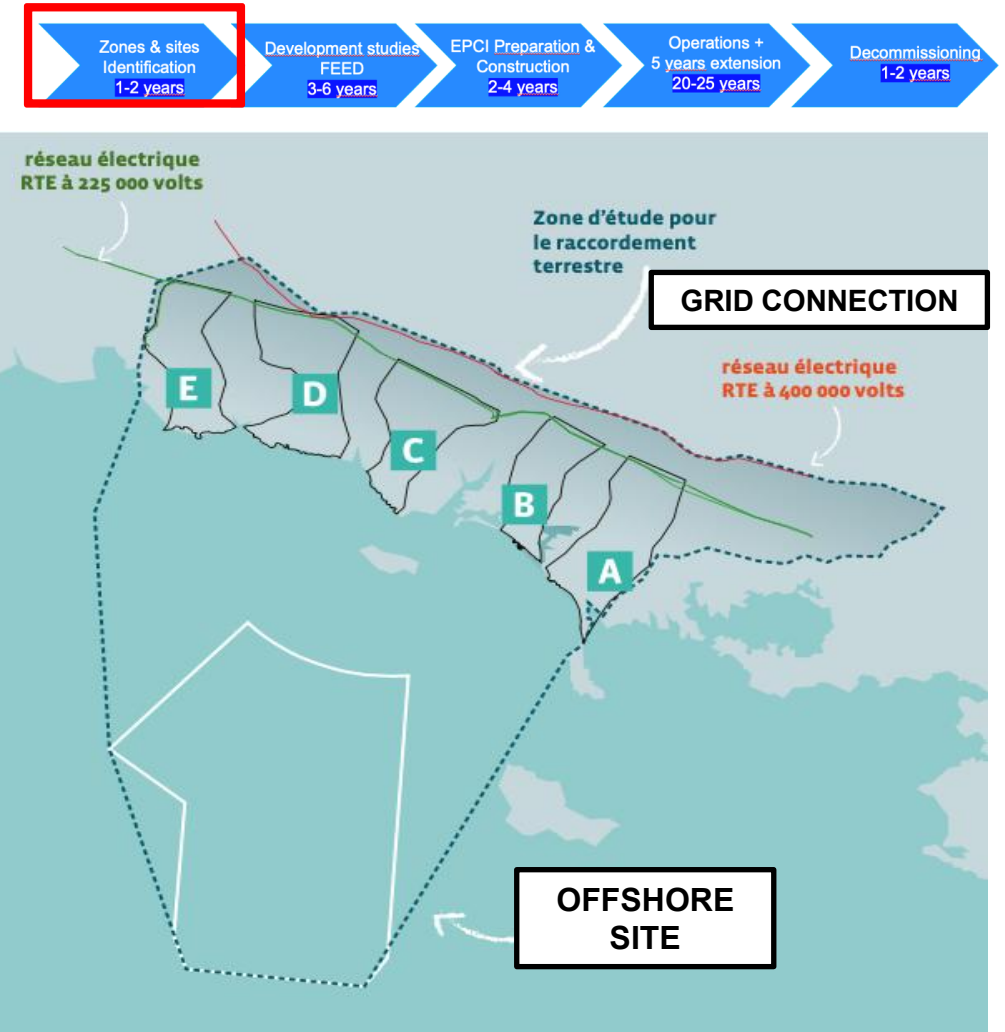
Offshore Wind: a typical project schedule

Project development



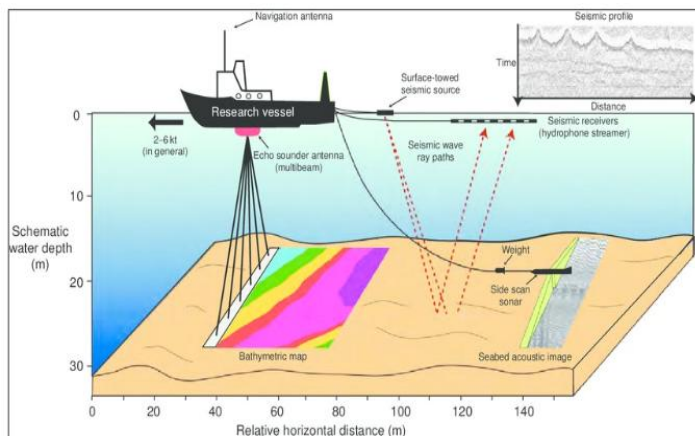
Zones & Sites Identification

- ◆ Initial screening of potential site(s) vs marine, military....
- ◆ Local authorities offer potential areas for lease
- ◆ Preliminary studies to select potential locations for
 - Offshore wind farm
 - Onshore grid connection
- ◆ Prepare tender documents including :
 - Technical details
 - Commercial conditions
 - Selection criteria
- ◆ Tender issued to potential developers or consortium
- ◆ Bids submitted
- ◆ Selection of developer (or developers if several zones offered)



Project Development : Environment Analysis

Geotechnical-meteocean



Biodiversity

Water Quality



Coastal and Terrestrial Habitat



Marine Mammals and Sea Turtles



Avian and Bats



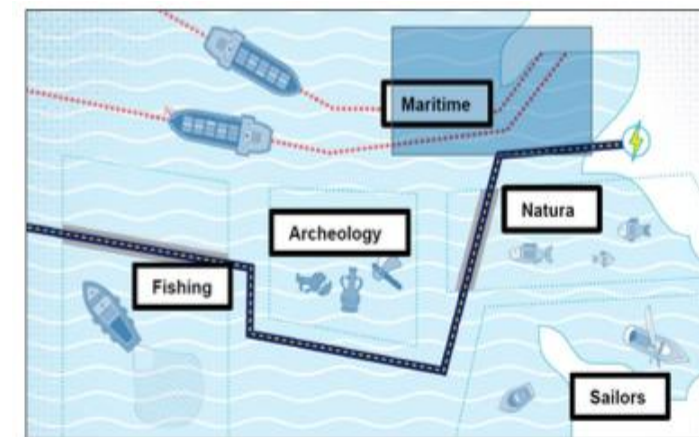
Benthic and Shellfish



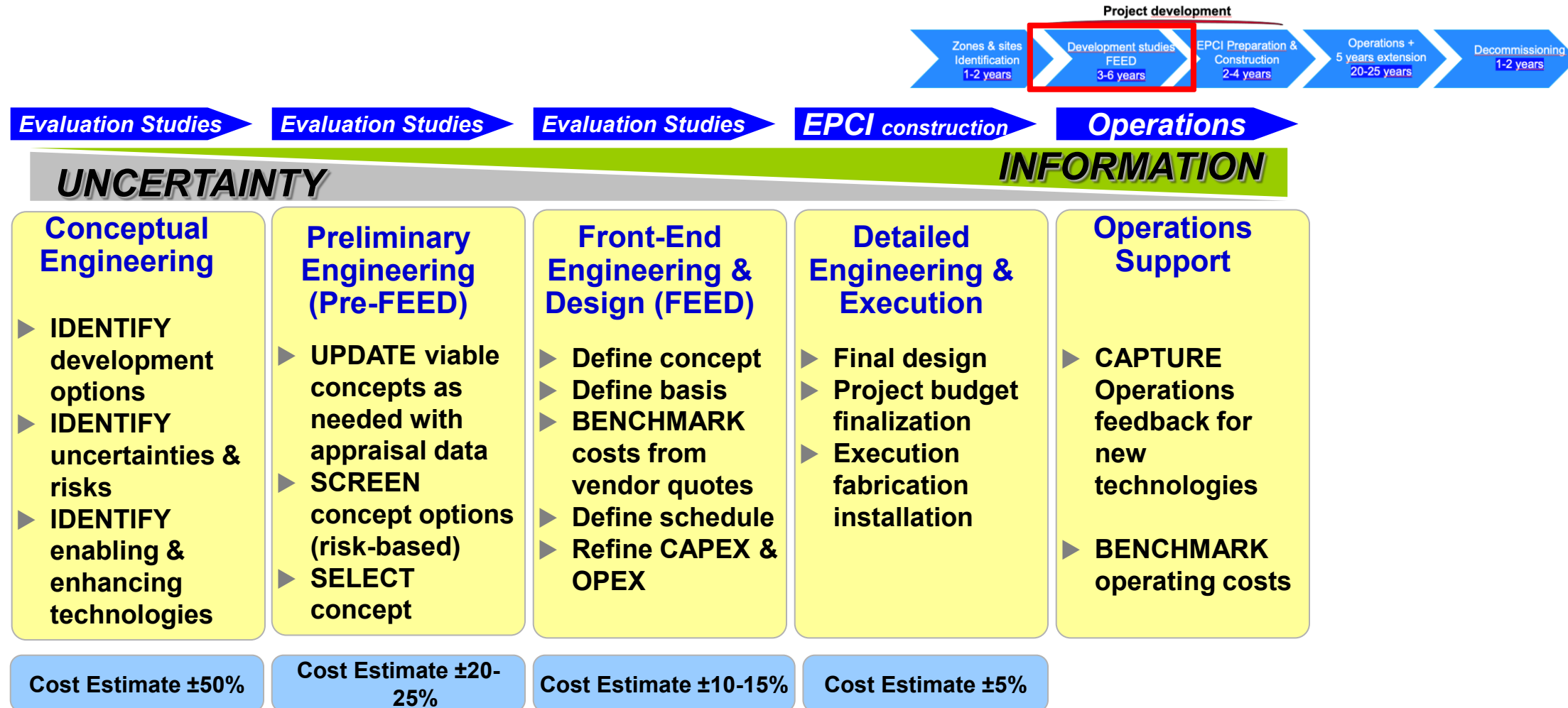
Finfish and Essential Fish Habitat



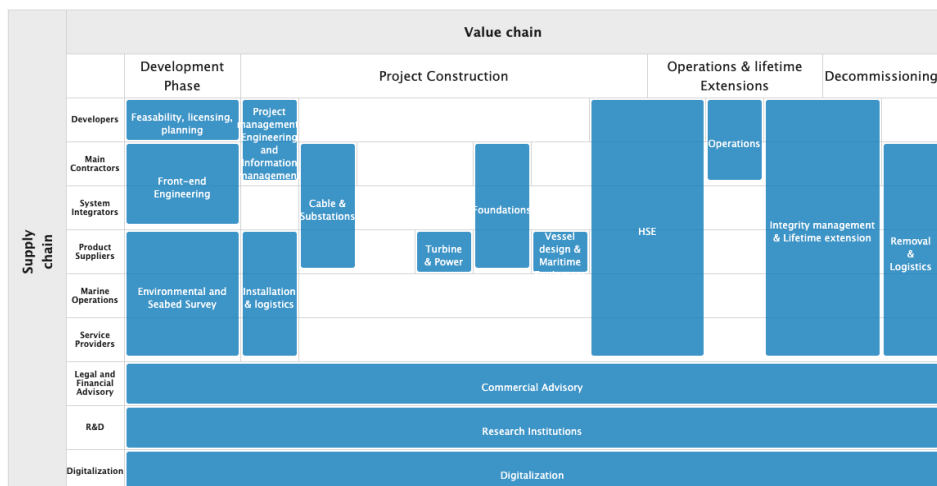
Stakeholders



Project Development : Engineering Studies

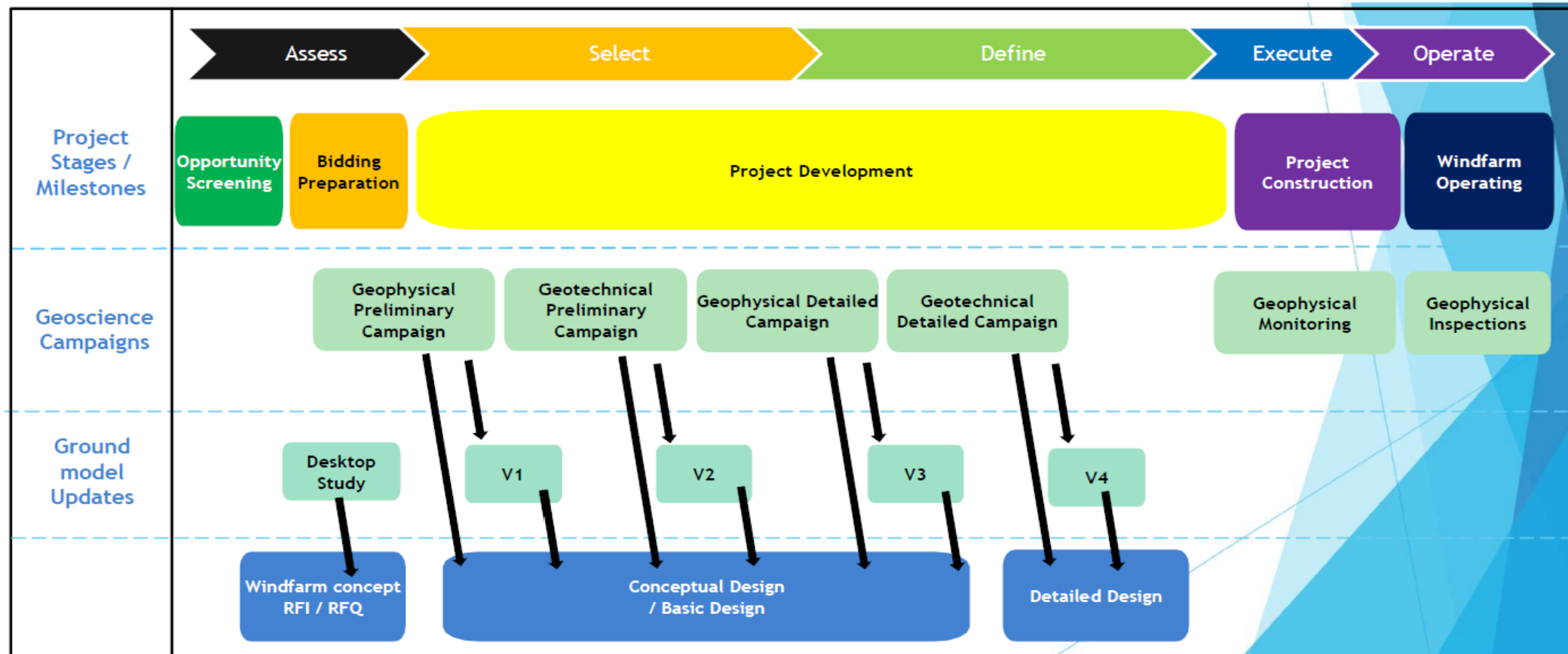


Project development : Procurement & Construction



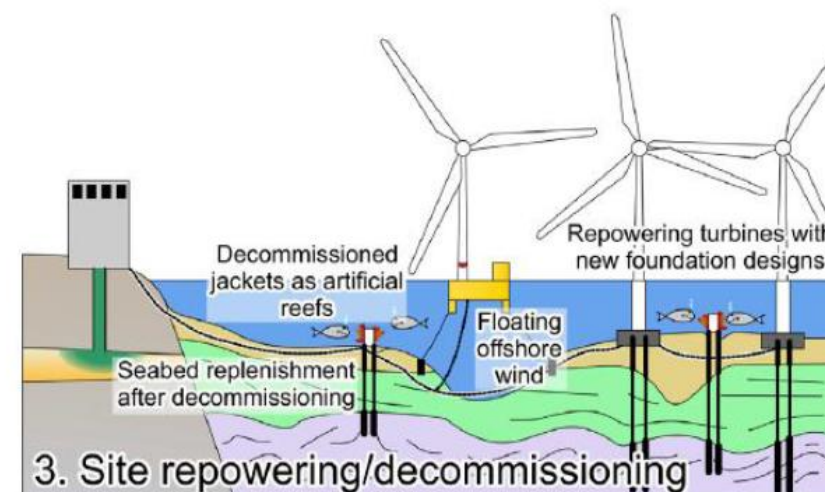
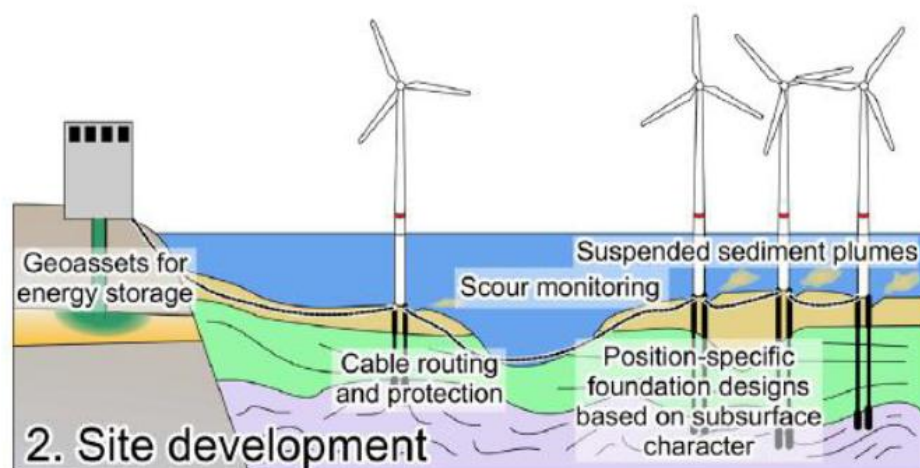
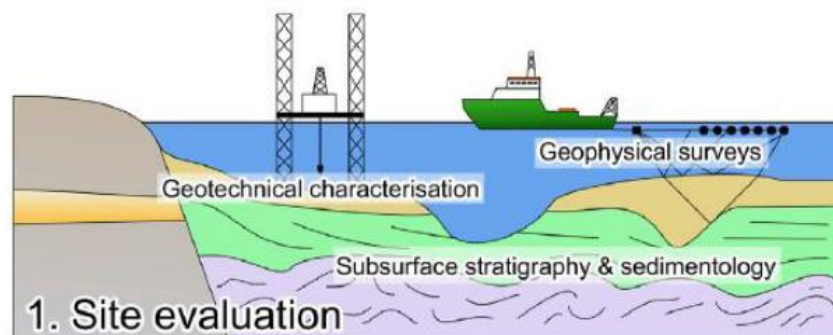
Offshore Wind: A zoom on Geosciences

Geoscience inputs in wind project development



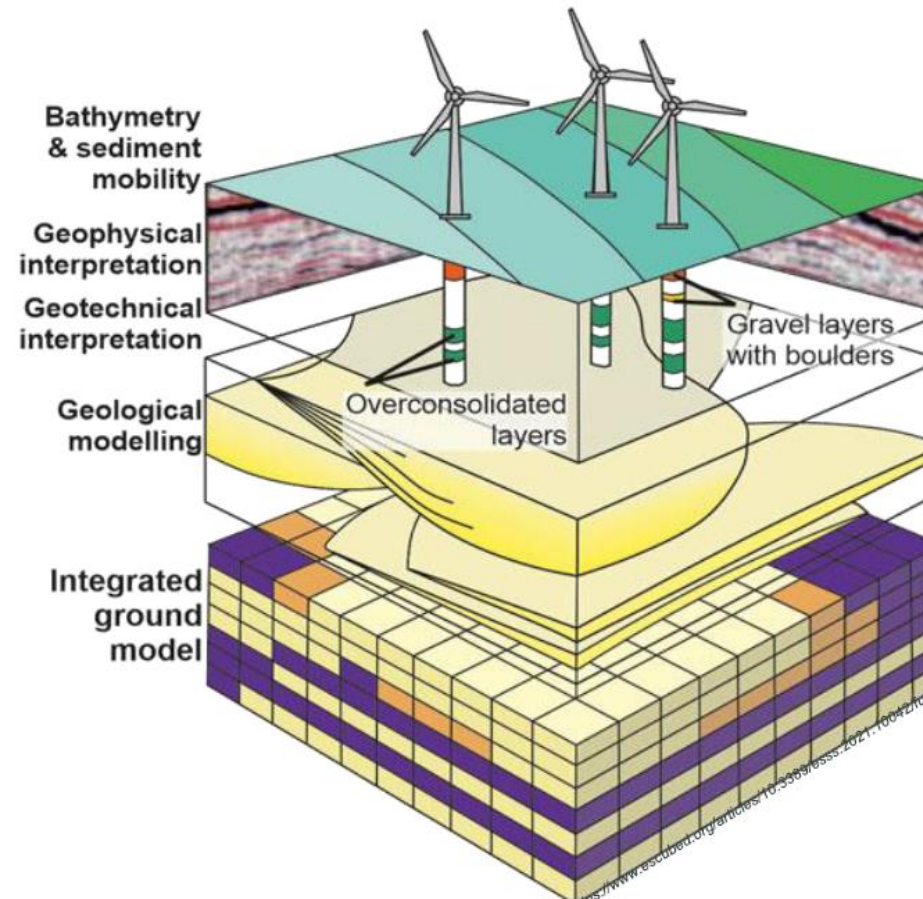
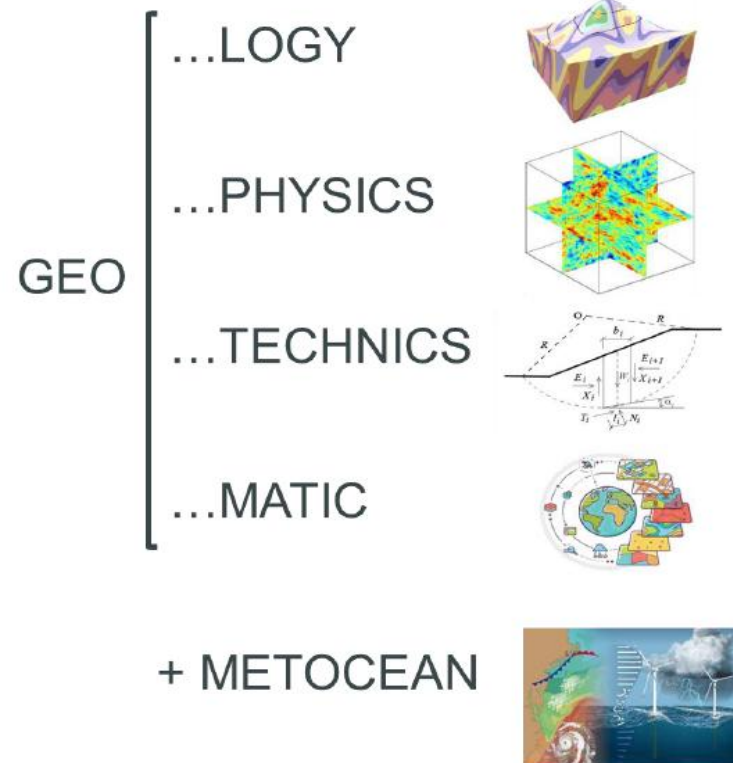
Offshore Wind: A zoom on Geosciences

Geoscience Roles in Offshore Wind farm Lifetime



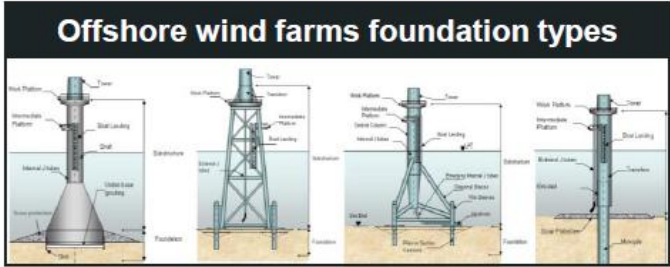
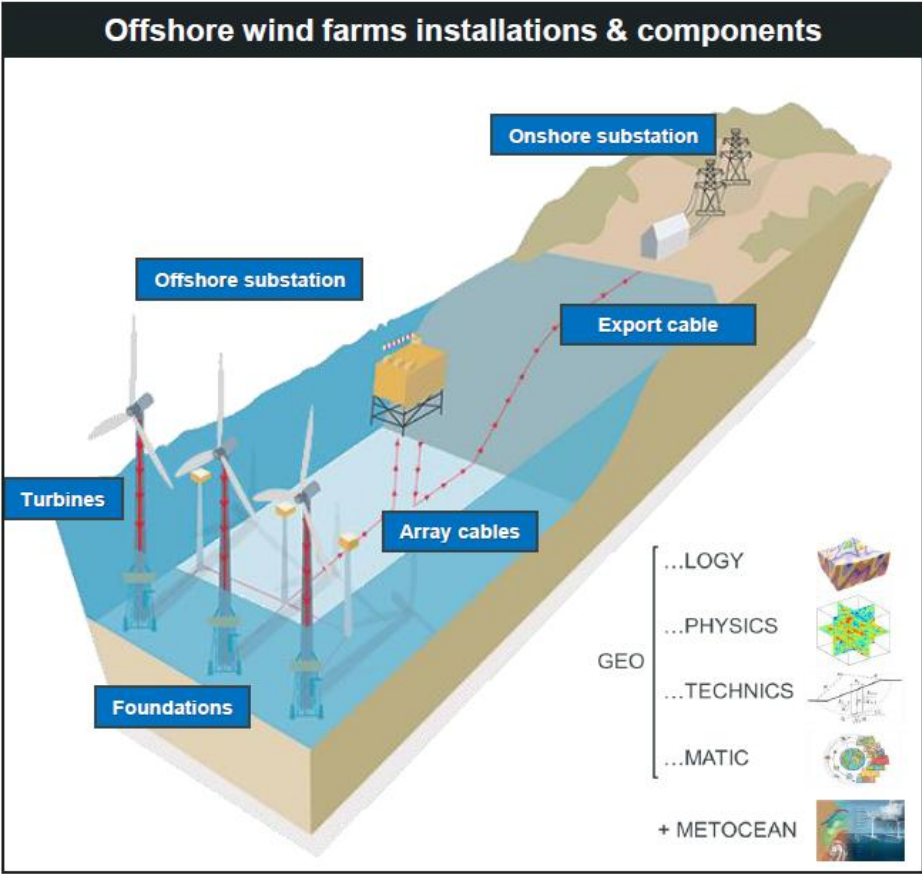
Offshore Wind: A zoom on Geosciences

Geoscience disciplines required in wind energy



Offshore Wind: A zoom on Geosciences

Offshore wind Geoscience objectives



TPA
Sharing Experience

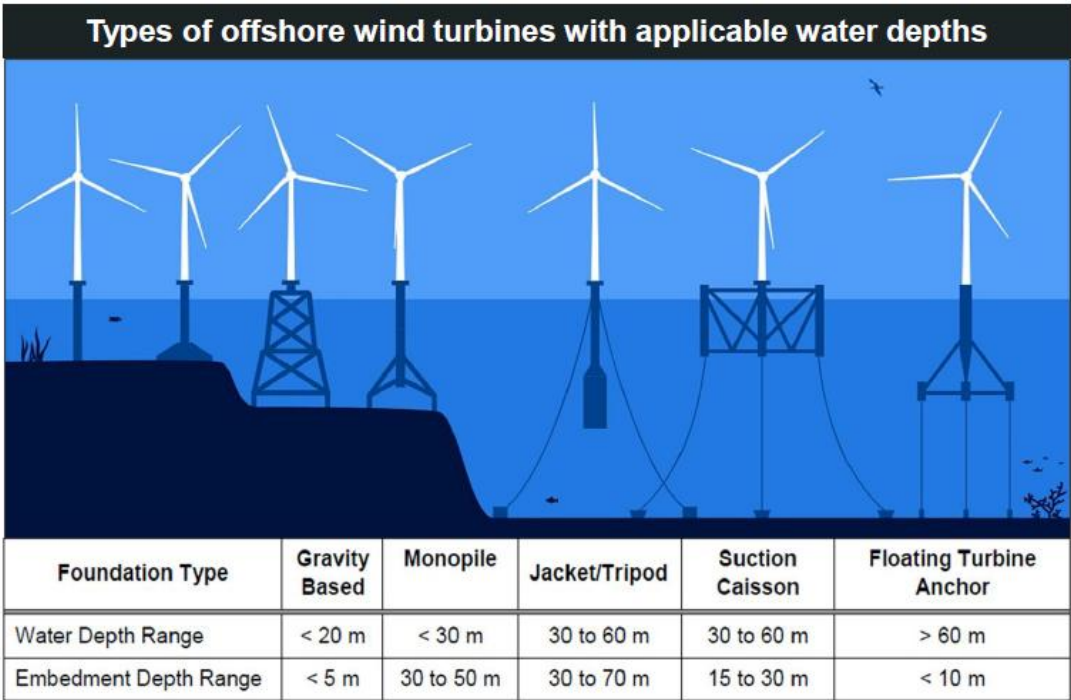


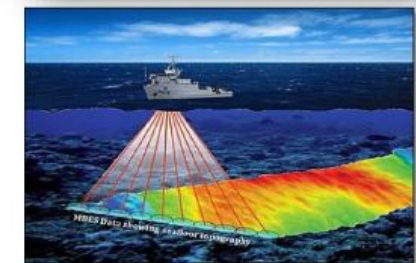
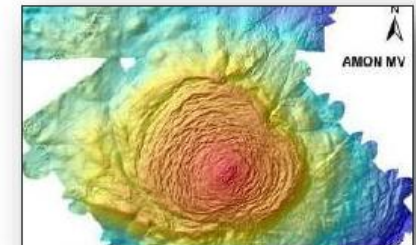
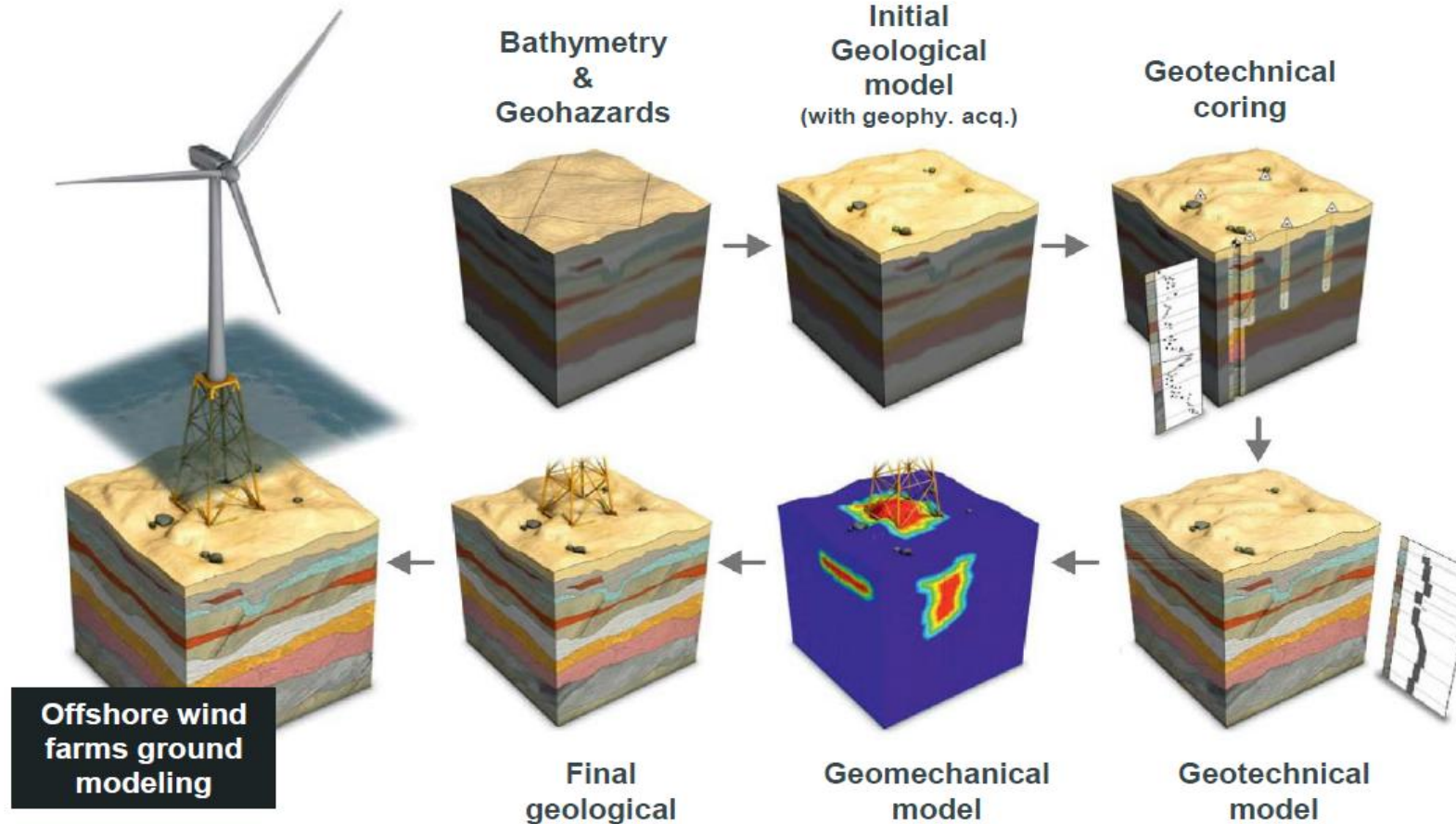
Image: DHI website - Table: Fugro



Offshore Wind: A zoom on Geosciences

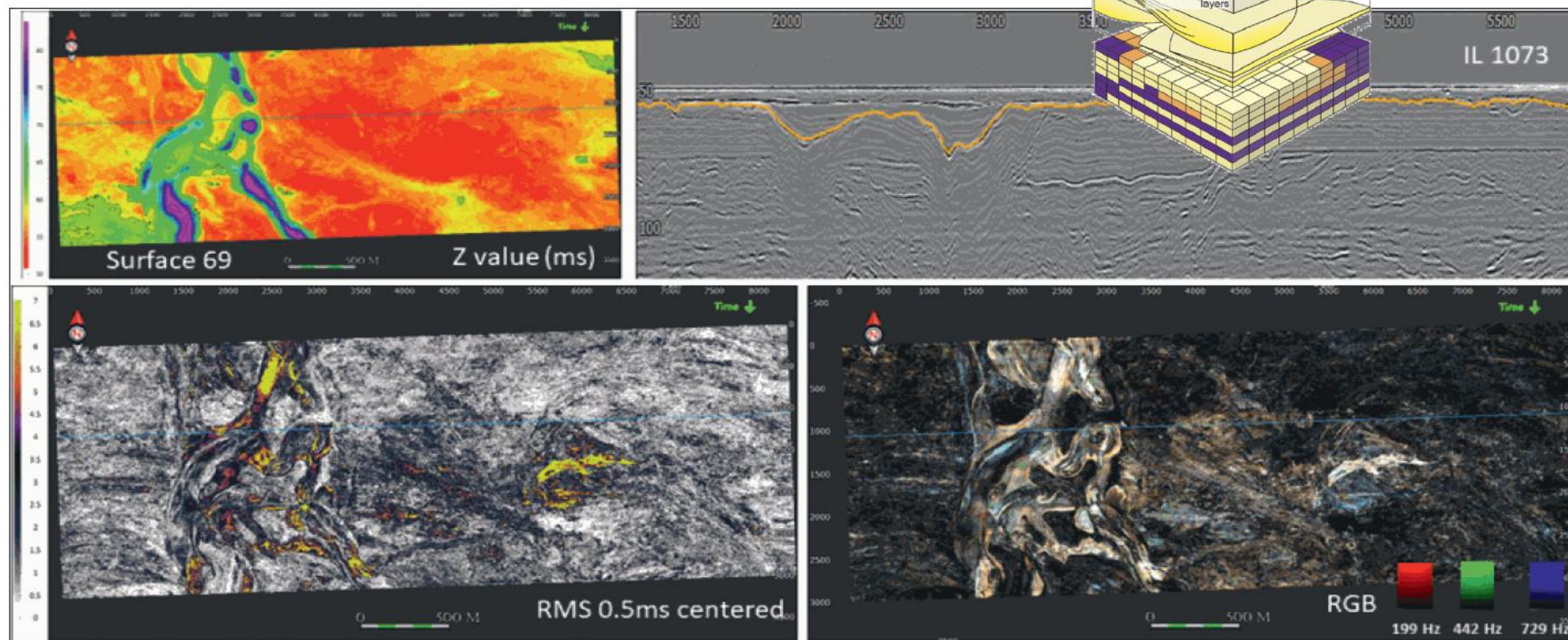
Offshore wind Geoscience inputs in project development

TPA
Sharing Experience



Offshore Wind: A zoom on Geosciences

Offshore wind Seismic innovations



(Durot et al., 2023, modified)

Source: Nicolas Nosjean

Offshore Wind installations

A Zoom on the turbine selection – An old model!

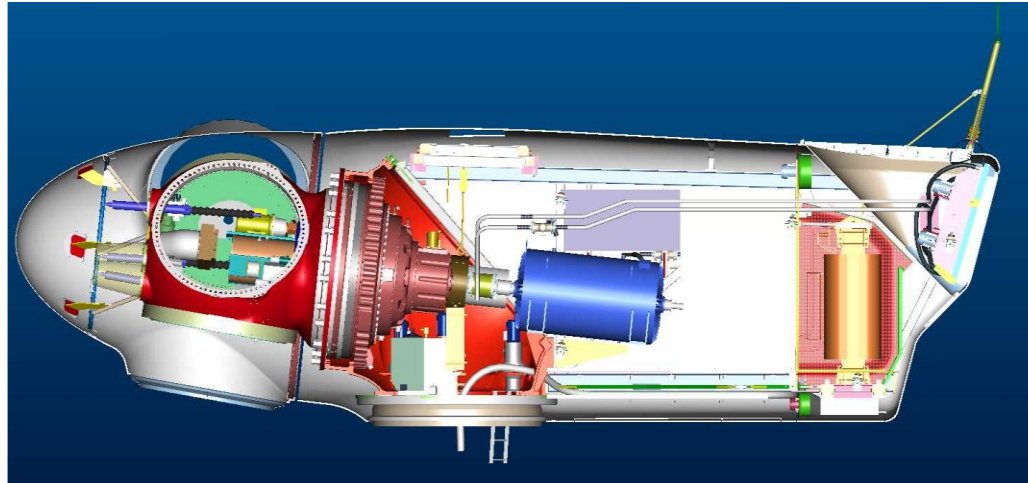


TurbinePower	3MW
Turbine AXIS Height above sea	70 à 75 m
Rotor diameter	90 à 100 m (tri-blade)
Rotor rotation speed	10 à 15 tr/mn

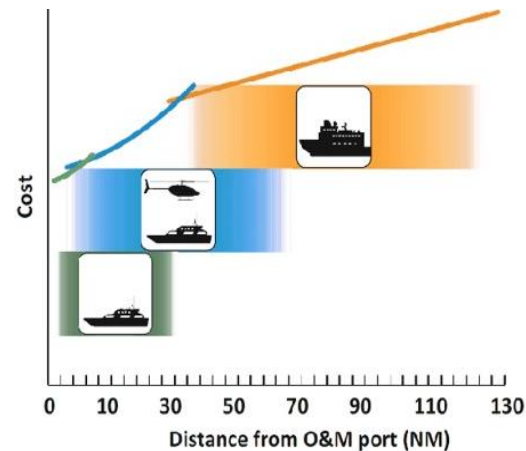
Operating
conditions

Nominal Wind speed	13 m/s
Minimum Wind speed	4 m/s
Maximum Wind speed	25 m/s

Design extrem speed	72 m/s, 3 secondes
Power control through blade Orientation System	



Operations & Maintenance



Offshore Wind Technology

Bremerhaven site (Germany) and Saint-Nazaire (France)

Construction – Installation - Maintenance



Source: Areva Wind/WeserWind GmbH

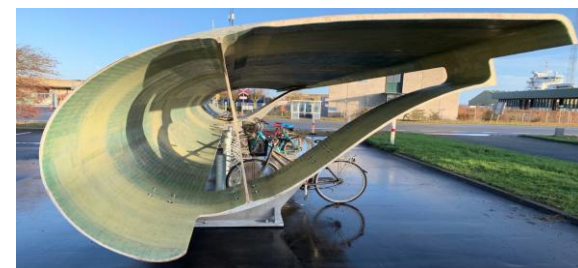
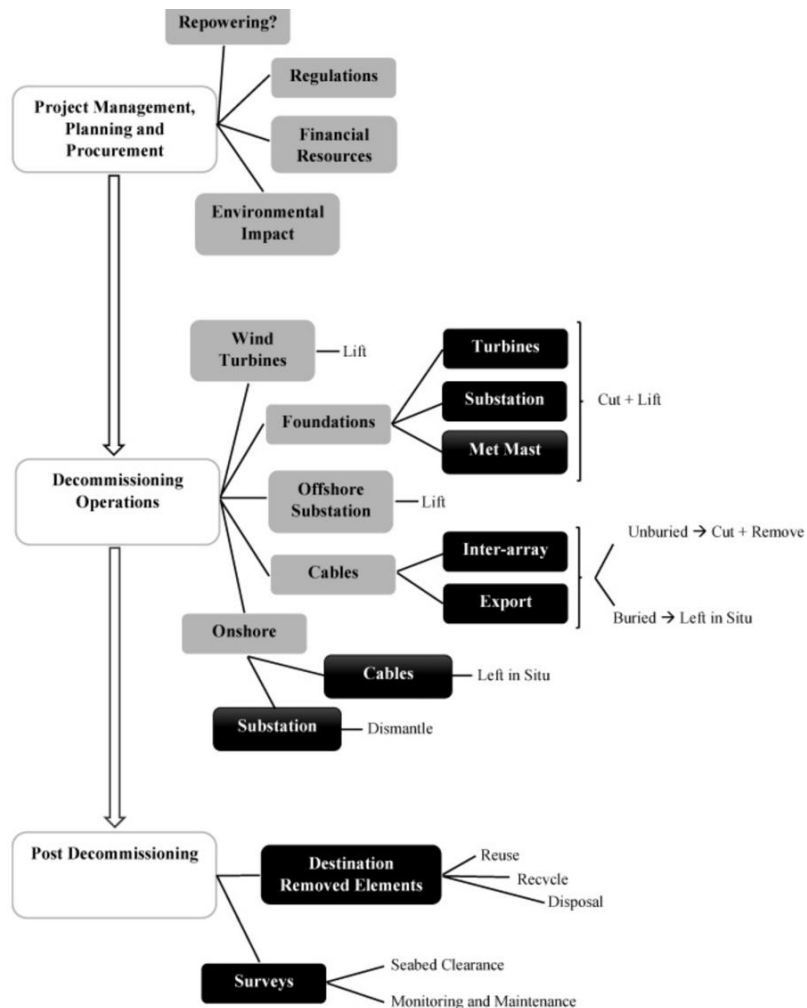


Wind Offshore equipment – Saint-Nazaire/France

New Power: 12 MW - New rotors: 750 tonnes



Decommissioning

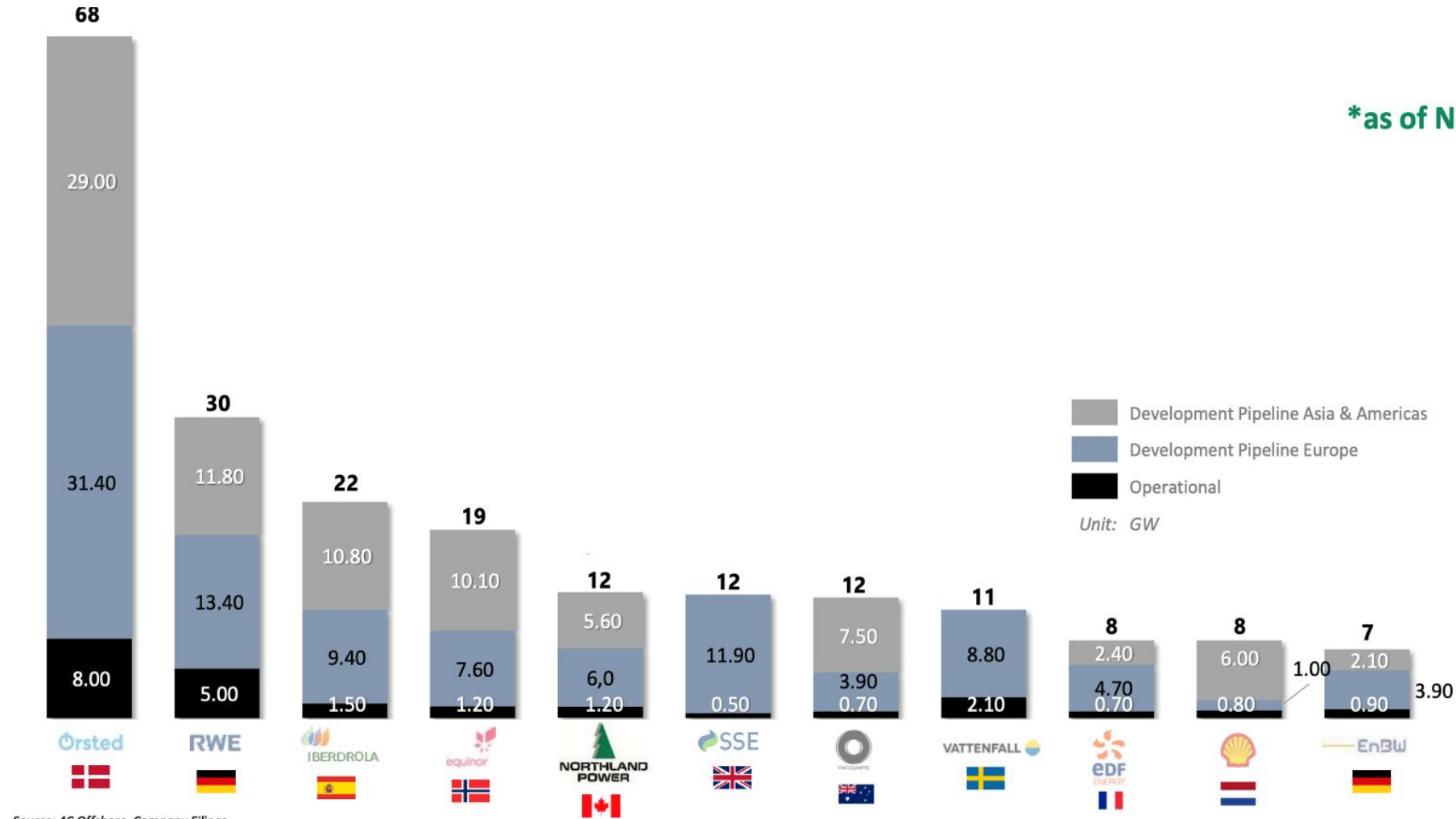


**Vindeby 5 MW
Denmark
Installed 1991 /
retrieved 2017**



The key Developers

*as of Nov 2021

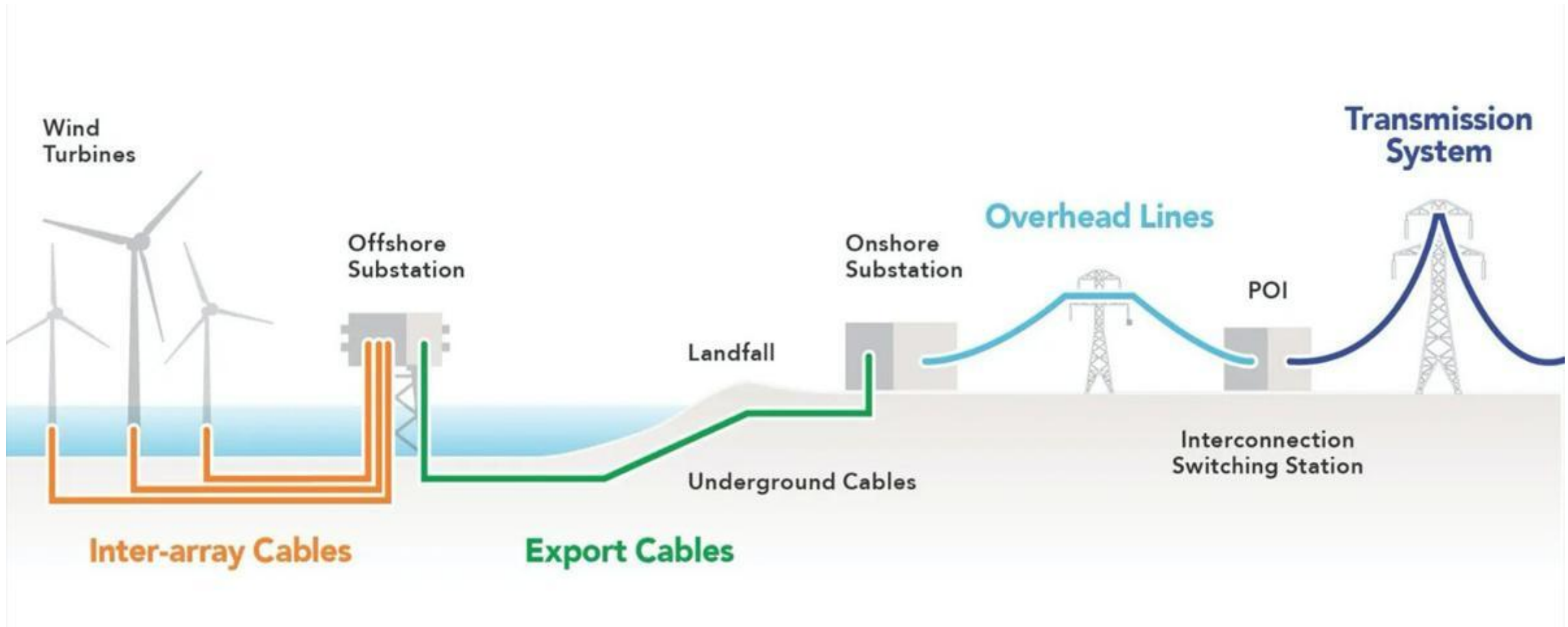


Source: 4C Offshore, Company Filings.

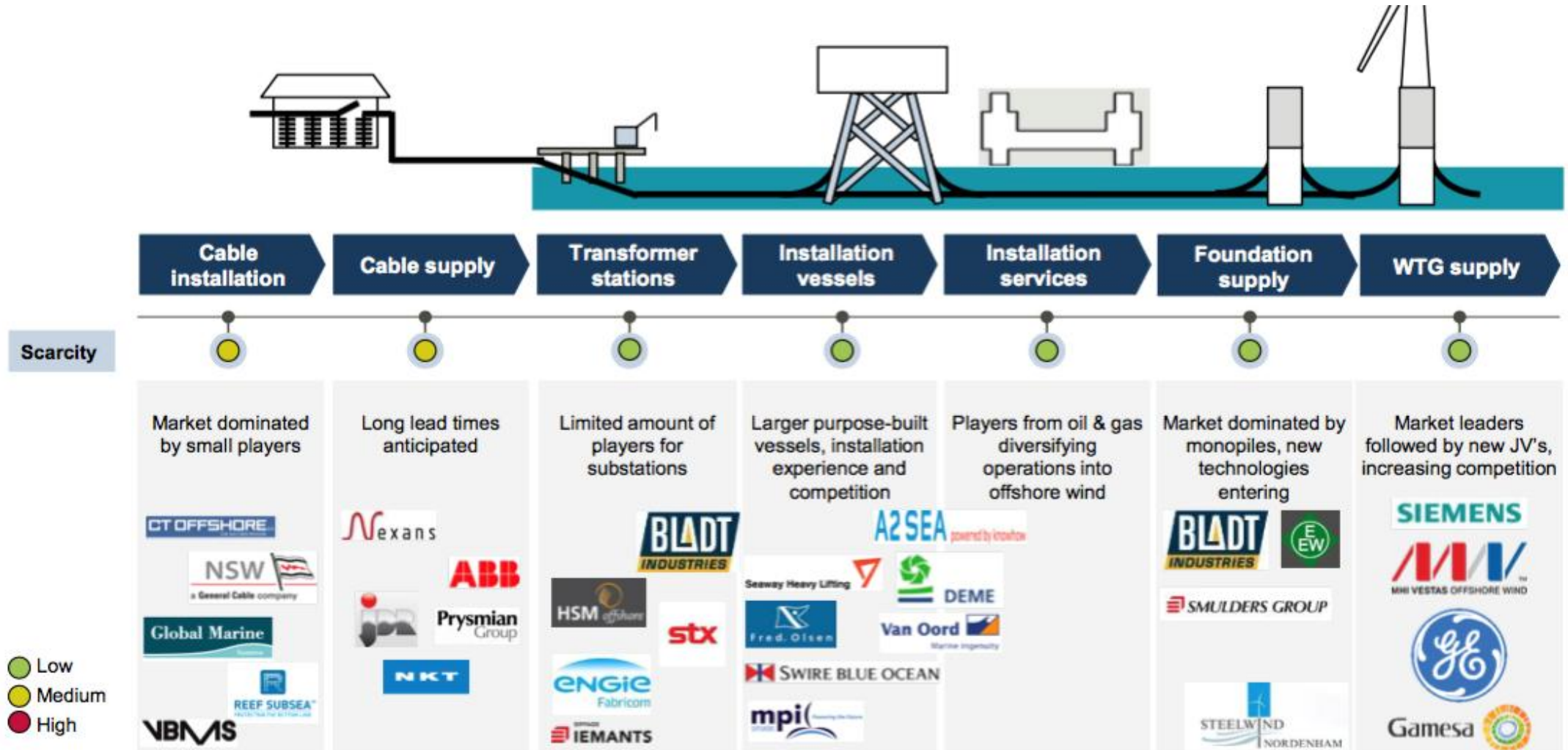
Source: Northland Power website



Offshore Wind Farm: The main components

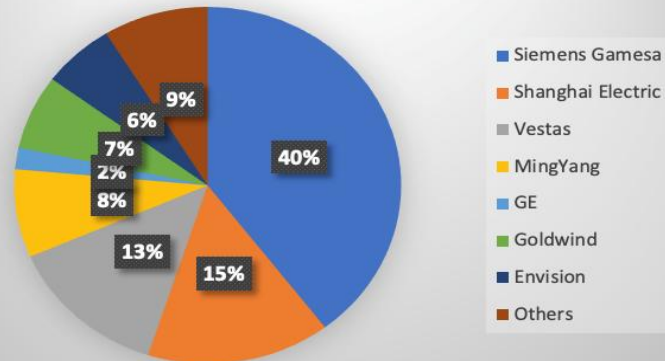


The supply chain

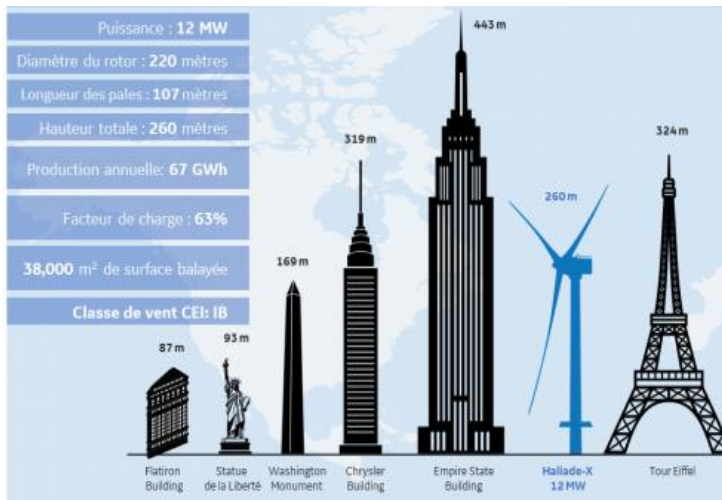


WTG (Wind Turbines Generators)

WTG Key Suppliers



14 MW GE-ALSTOM

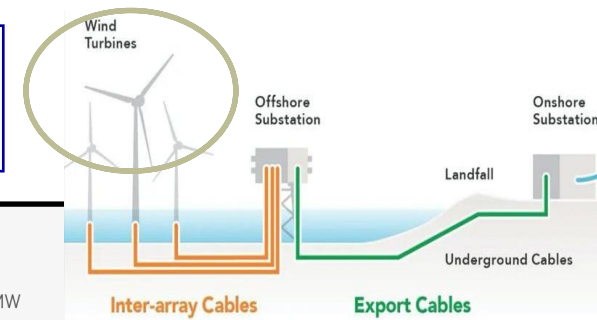


14 MW SIEMENS GAMESA

SG 14-222 DD

IEC class	I, S
Nominal power	14 MW
Rotor diameter	222 m
Blade length	108 m
Swept area	39,000 m²
Hub height	Site-specific
Power regulation	Pitch-regulated, variable speed

227



15 MW MHI VESTAS



Swept area : 43 000m²
Rotor diameter : 236m
Blade length : 115,5m
Serial production : 2024



WTG : the chinese suppliers



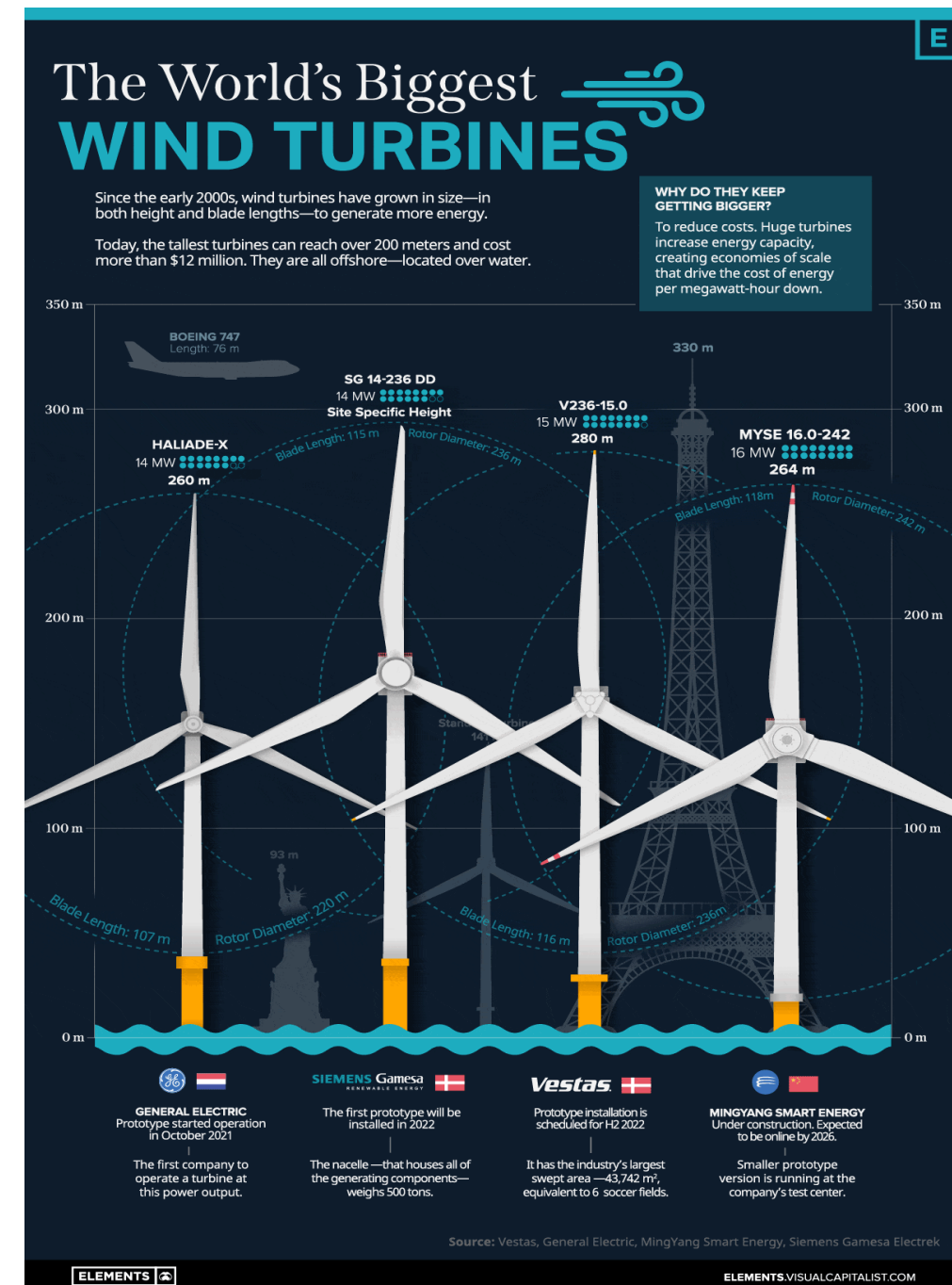
Chinese announcements **EARLY 2023 : 18 MW the new standard**



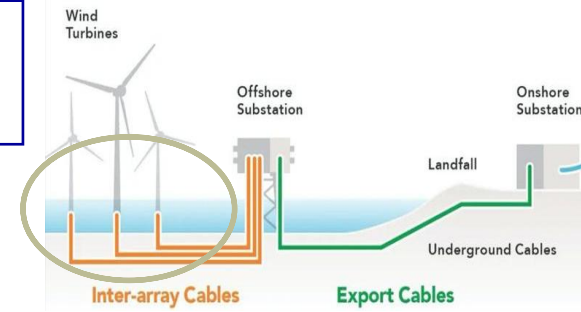
Image: CSSC Haizhuang Wind Power



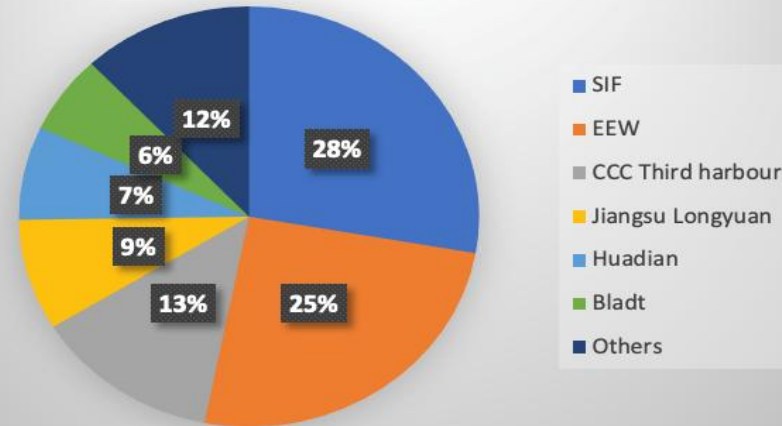
Source: MingYang Smart Energy



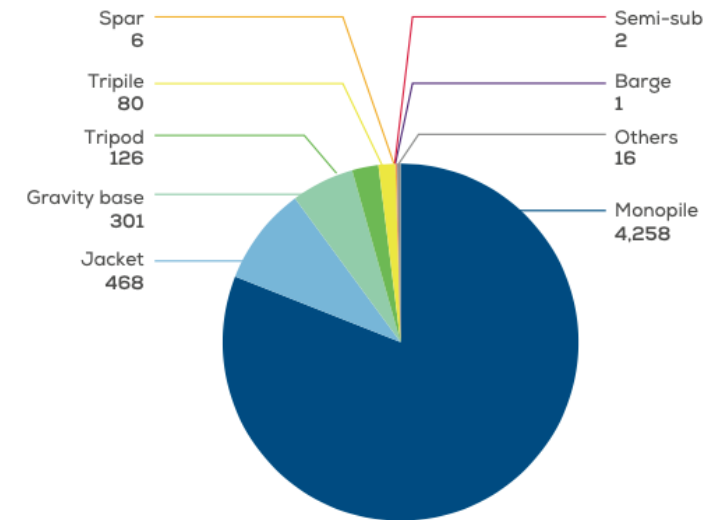
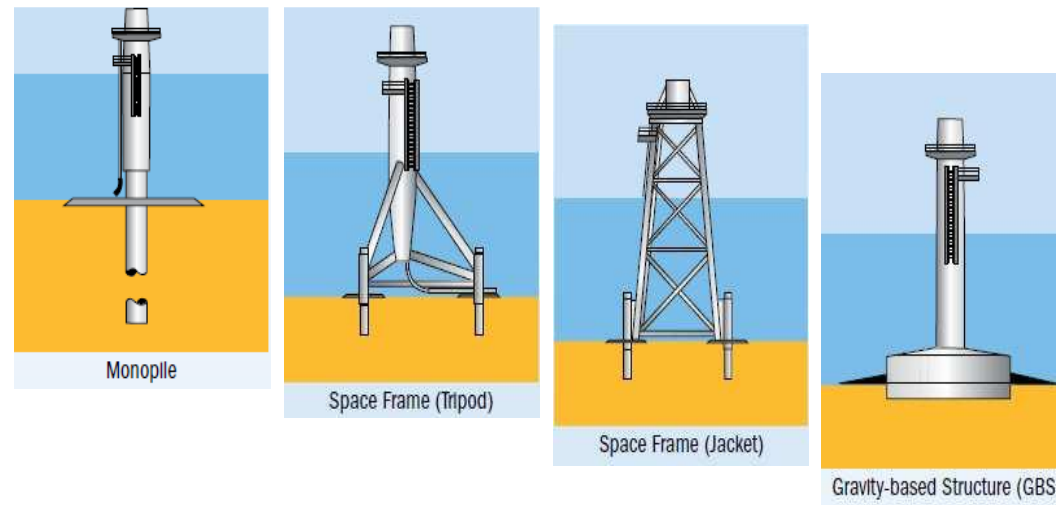
Foundations



Foundation Key Suppliers

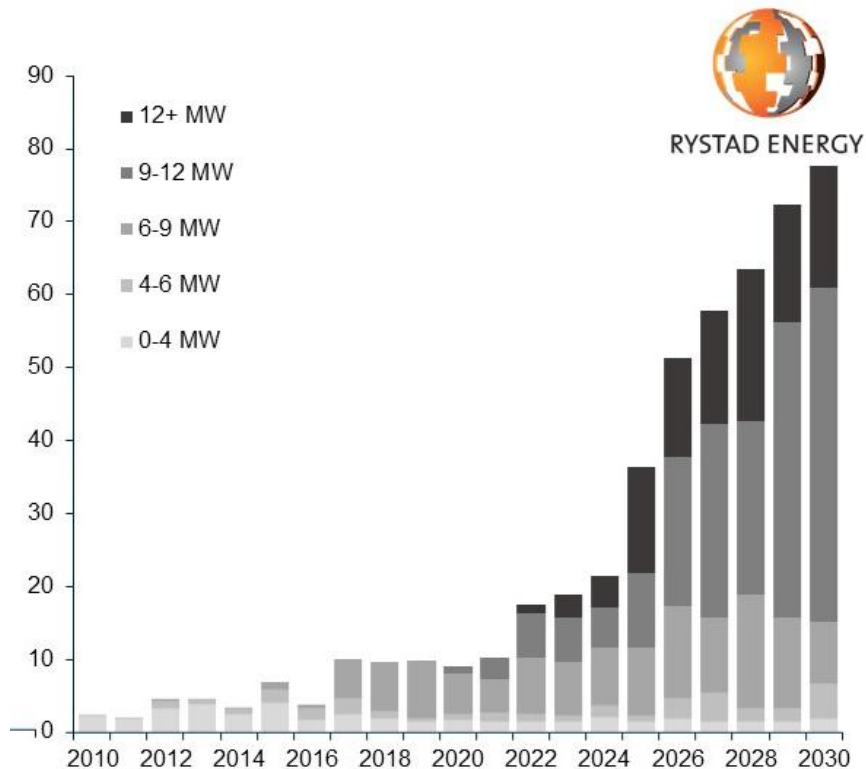


WATER DEPTH	FOUNDATION	DEPTH [m]
	Gravity-based foundations (GBF)	<20 ¹⁾
	Monopile	10-30 ¹⁾
	Tripod/-pile	25-50
	Jacket	20-60
	Floating	> 50



Installation Vessels

Turbine installation vessel demand*
Vessel years



JACK-UP VESSELS

Application

- > Offshore wind farms are constructed by jack-up vessels
- > Mostly, jack-ups load material in harbors, carry it to site and install it

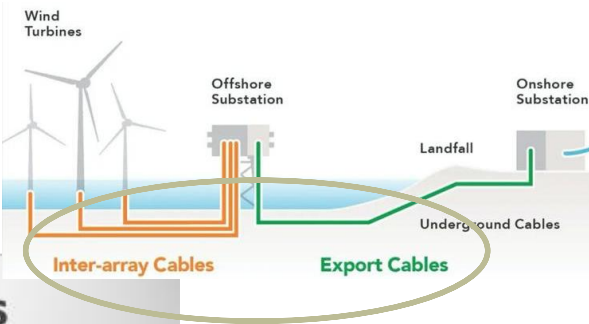
History

- > Vessels from offshore oil & gas industry deployed for first wind farm installations
- > Major bottleneck around 2008 for offshore wind installation vessels
- > Some 15 new vessels are being built that are tailored to the needs of offshore wind energy

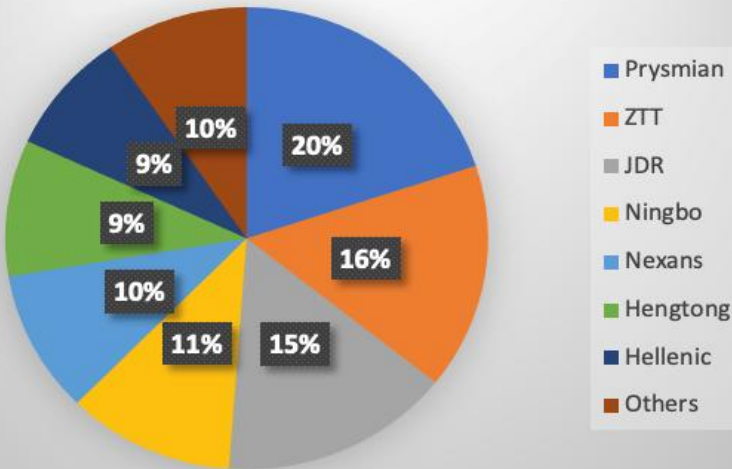
NEW GENERATION OF VESSELS



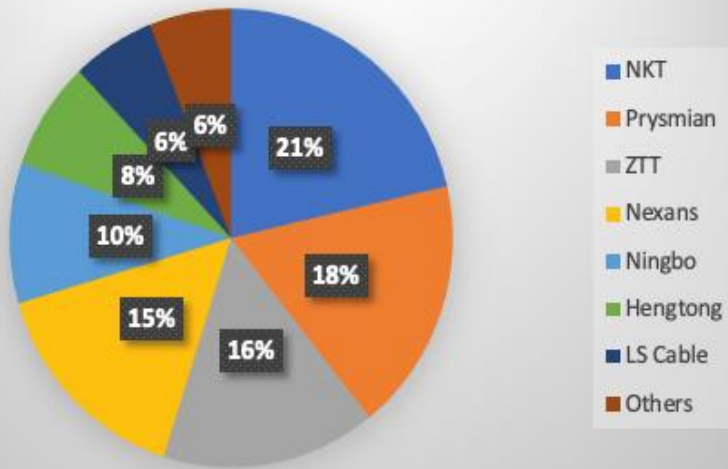
Array & export cables



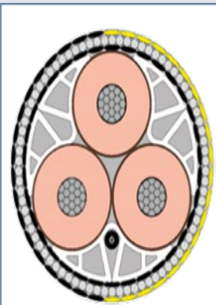
Array Cable Key Suppliers



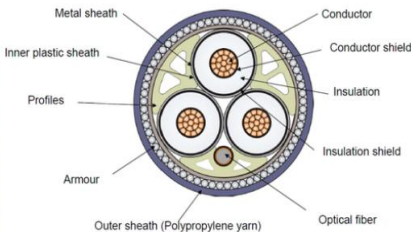
Export Cable Key Suppliers



Typical 66 kV cable design for offshore wind



Conductor	Copper or aluminum conductors longitudinally water blocked
Conductor screen	Extruded semi conductive compound
Insulation	EPR
Insulation screen	Extruded semi conductive compound
Screen	Individual Cu-tape screen on each phase
Fibre optic unit	Up to 3 FO units with metal tube
Lay up	Three power cores laid up with extruded fillers
Armour Bedding	Polypropylene yarns
Armouring	One layer of galvanized steel wires, flushed with bitumen
Outer protection	Polypropylene yarns in customisable colours

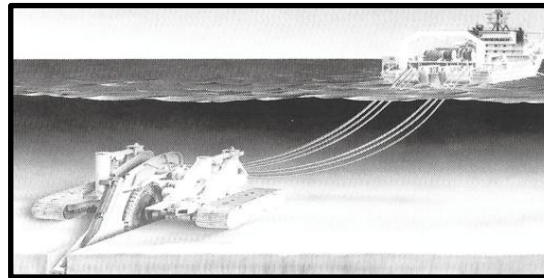


Electric cables installations



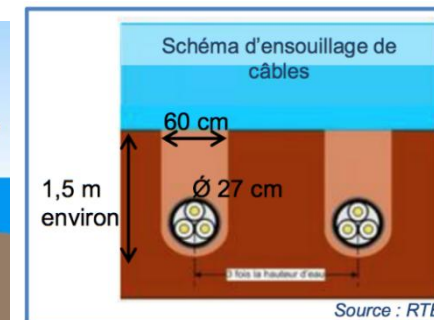
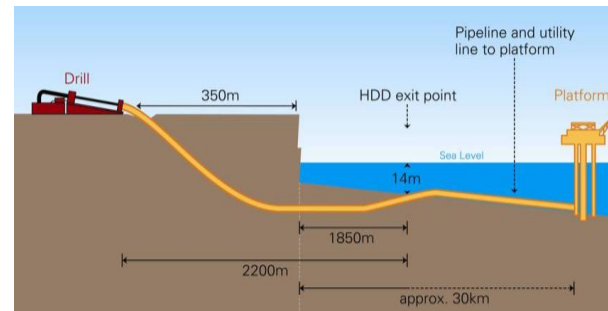
Array cables scope includes :

- Pulling on unmanned platforms
- Laying/trenching



Export cable scope includes :

- Shore approach
- Laying/Trenching
- Shallow water laying/trenching



Offshore substation supply

HVAC ($L < 100\text{km}$) : Small
2,000tons jacket/topsides
in UK, France, Denmark...

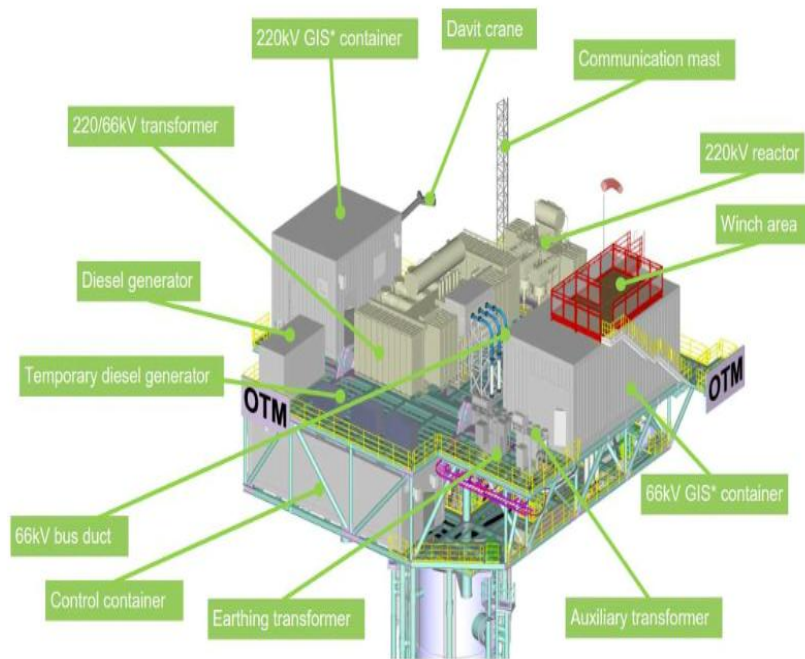
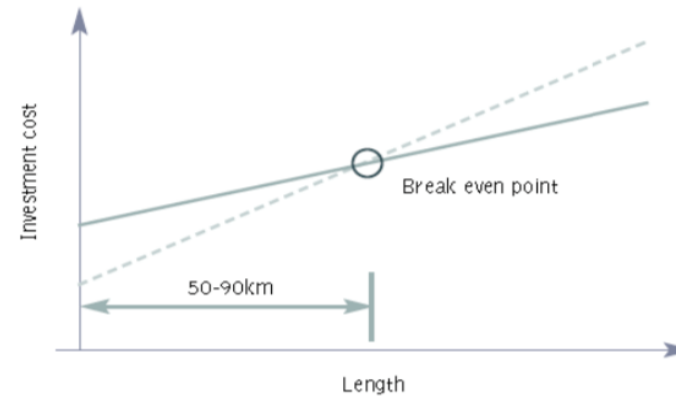
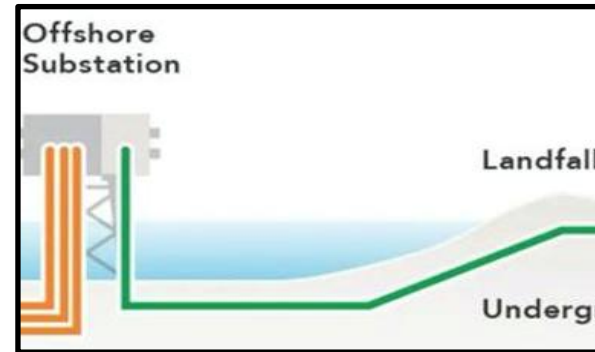
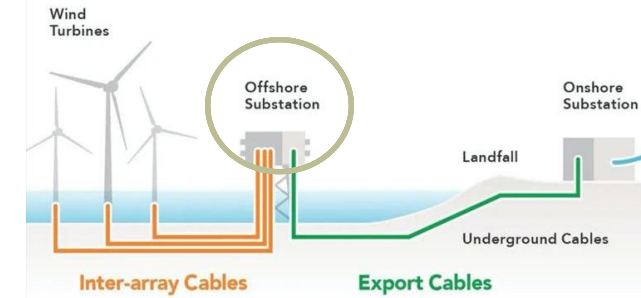


Image courtesy of Siemens. All rights reserved.

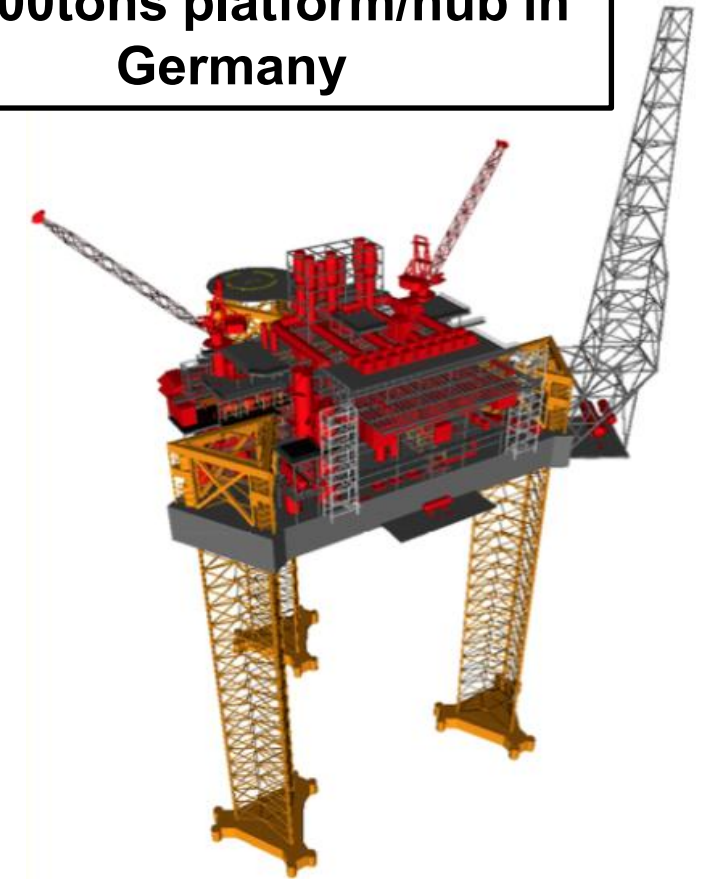


--- HVAC — HVDC

233



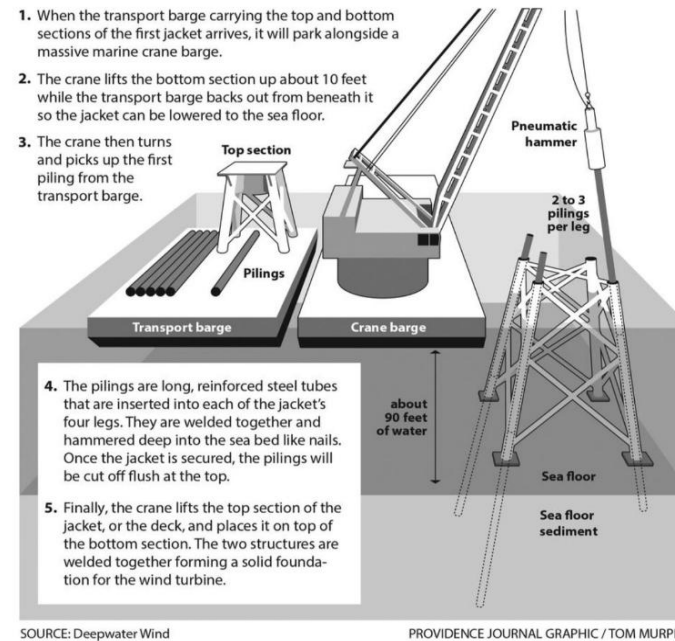
HVDC ($L > 100\text{km}$) : Large
20,000tons platform/hub in
Germany



TPA Toolbox Energy Book 7 – Renewables

Offshore substation installation

For **small substation platform** :
conventionnal installation method of the
Oil & Gas industry is used.

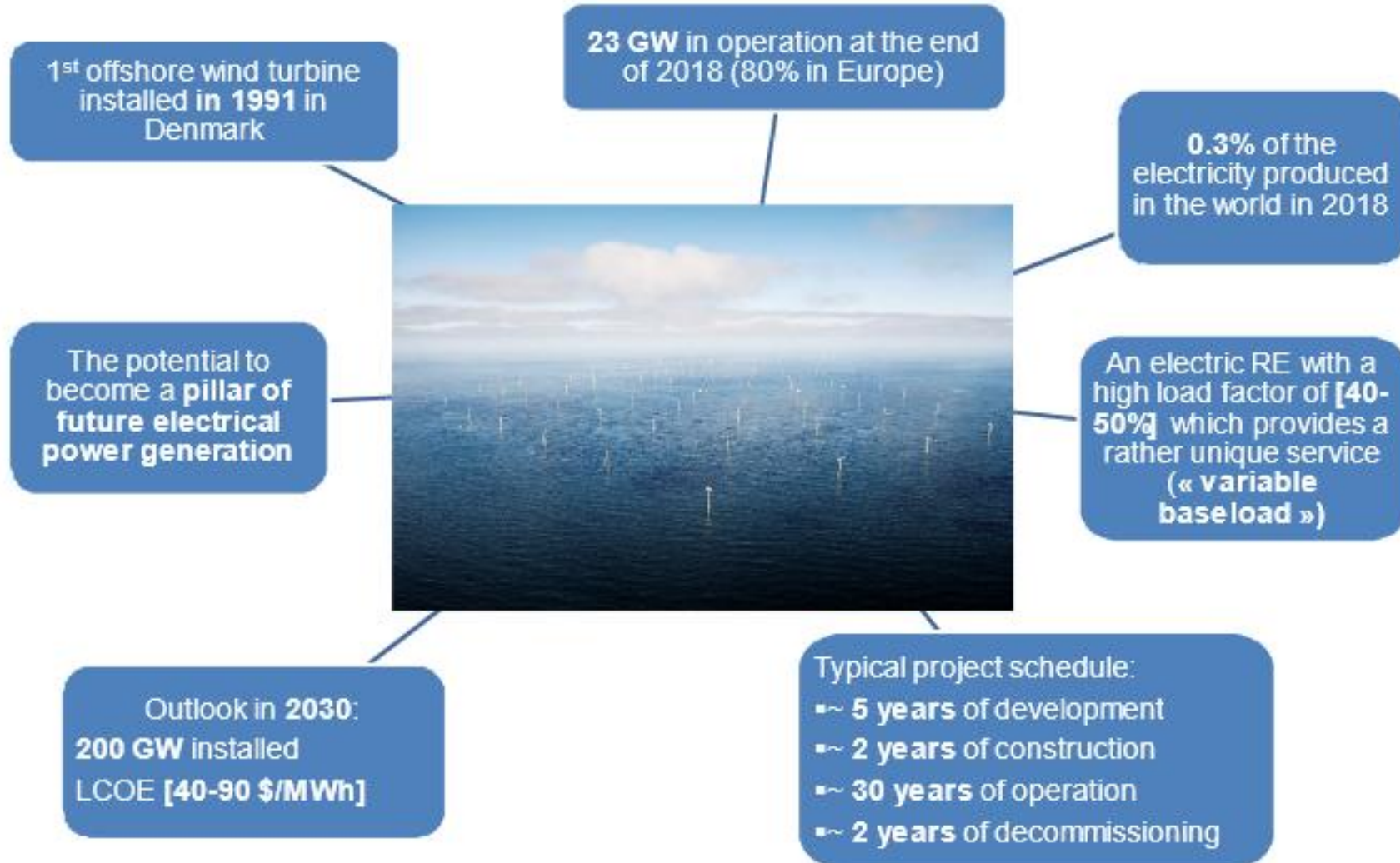


All solutions have been used for **large substation platform** installation offshore :

- Floatover
- Lifting
- Towing
- Jacking up...



Offshore Wind Key Facts



O.W.F. (Offshore Wind Farm) : the concept

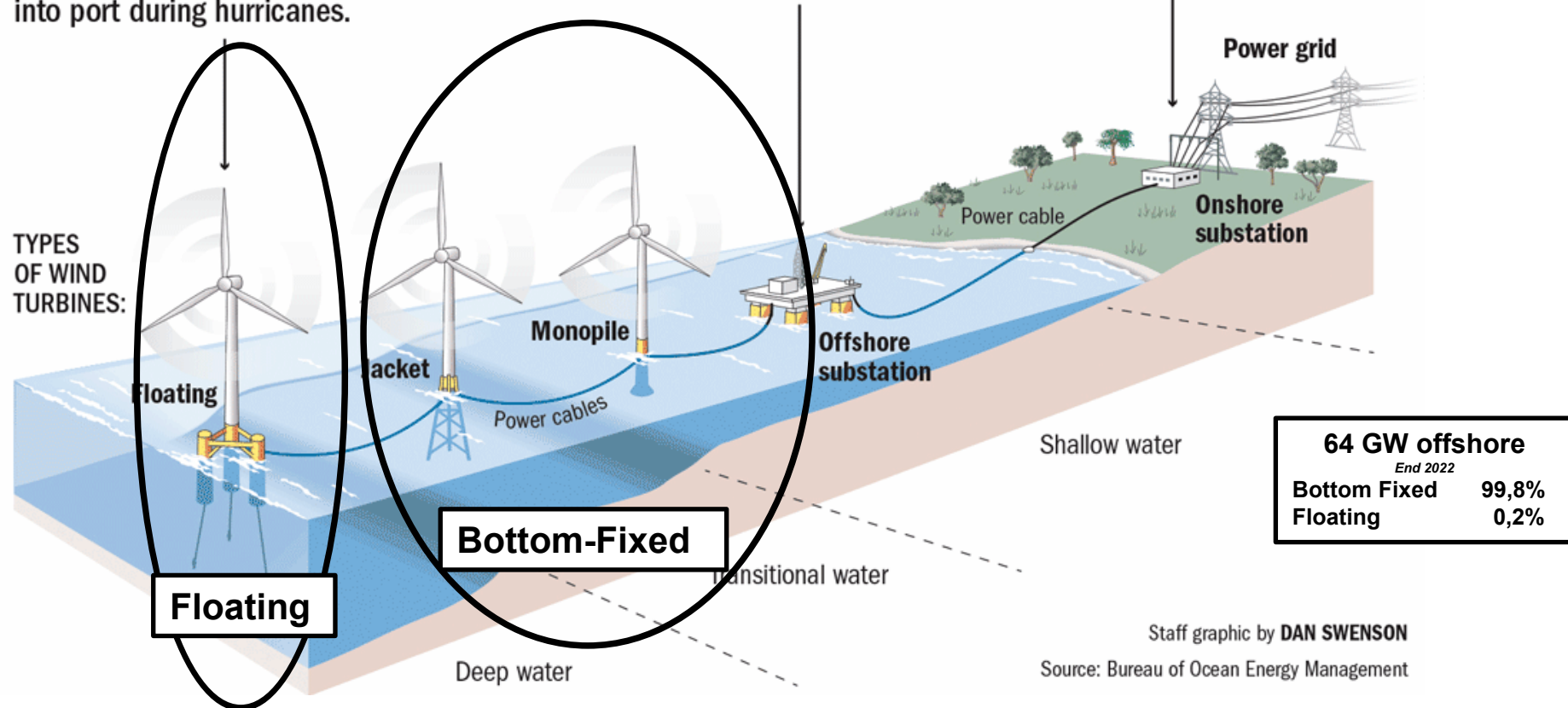
Onshore concept



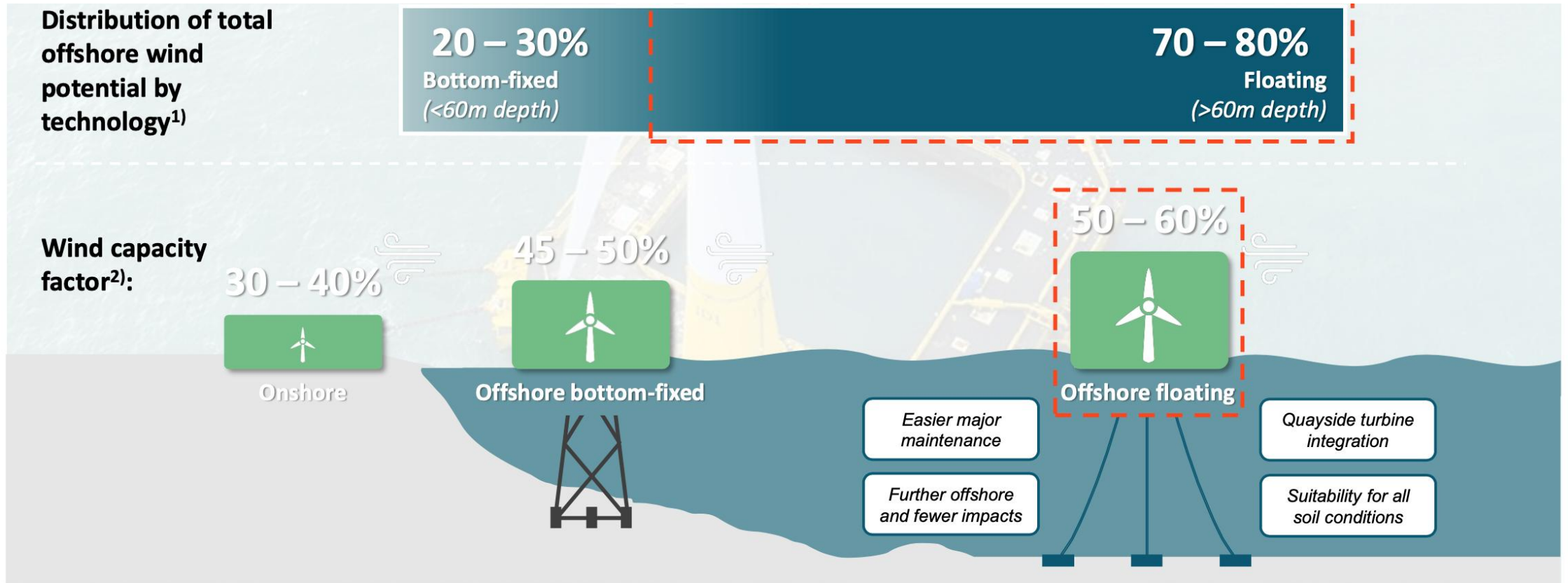
Turbines are often placed in groups in areas with optimal wind speeds. Most are stationary or fixed to a location in shallow water, but floating turbines could be used in deep water and hauled into port during hurricanes.

Energy captured by turbines is transmitted by cables to substations. Abandoned oil platforms could be repurposed and outfitted as offshore substations.

Electricity flows to an onshore substation linked to the power grid.



Numerous reasons to go offshore



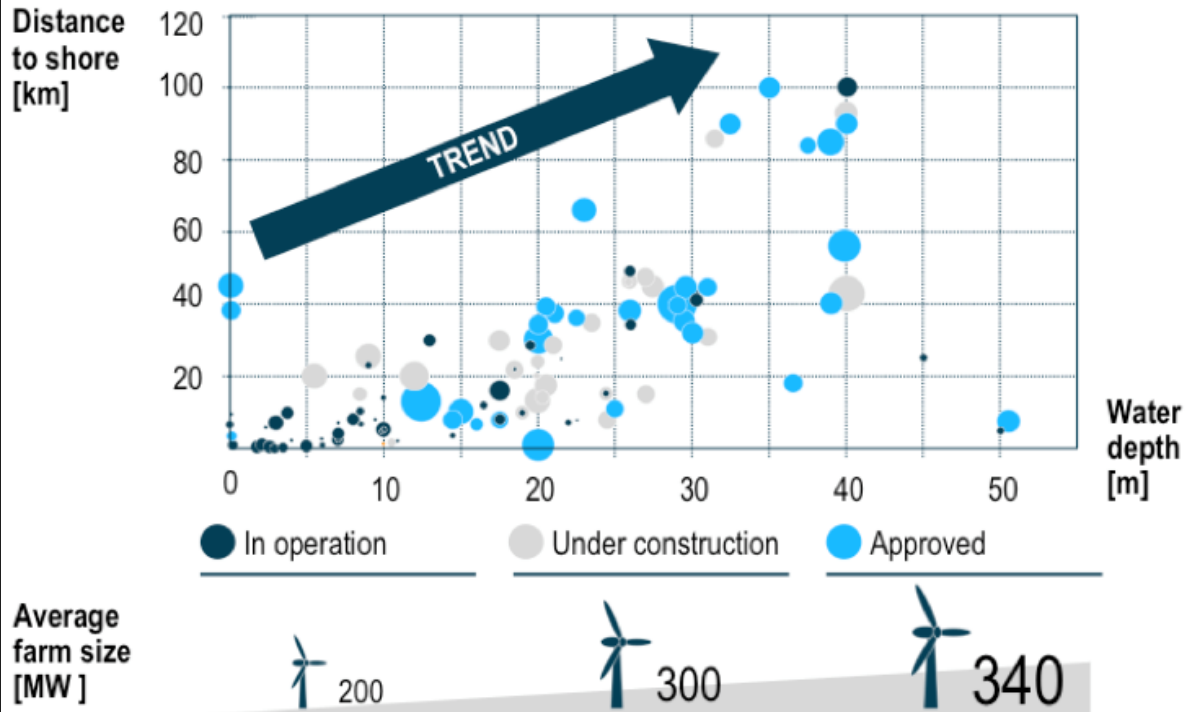
1) Estimated global distribution of potential by offshore wind technology based on geospatial analysis undertaken by EIA and the Imperial College London; 2) Capacity factor project dependent
Source: IEA (2019) Offshore Wind Outlook 2019; Wood Mackenzie Power & Renewables: The Momentum of Floating Wind and its Outlook Implications (Dec 19); Fortune Business Insights

BW ideal



O.W.F. trends : Further, Deeper & Larger

OFFSHORE WIND FARMS



TRENDS

- I FURTHER**
 - > Trend toward building wind farms further from shore
 - > Environmental laws (GER) and limited space close to shore are a driver for greater distance
- II DEEPER**
 - > Greater distance to shore usually leads to deeper water at site
 - > Deeper water requires new foundation solutions
- III LARGER**
 - > Larger wind farms allow improved fixed cost allocation
 - > Average size of approved projects is at 340 MW

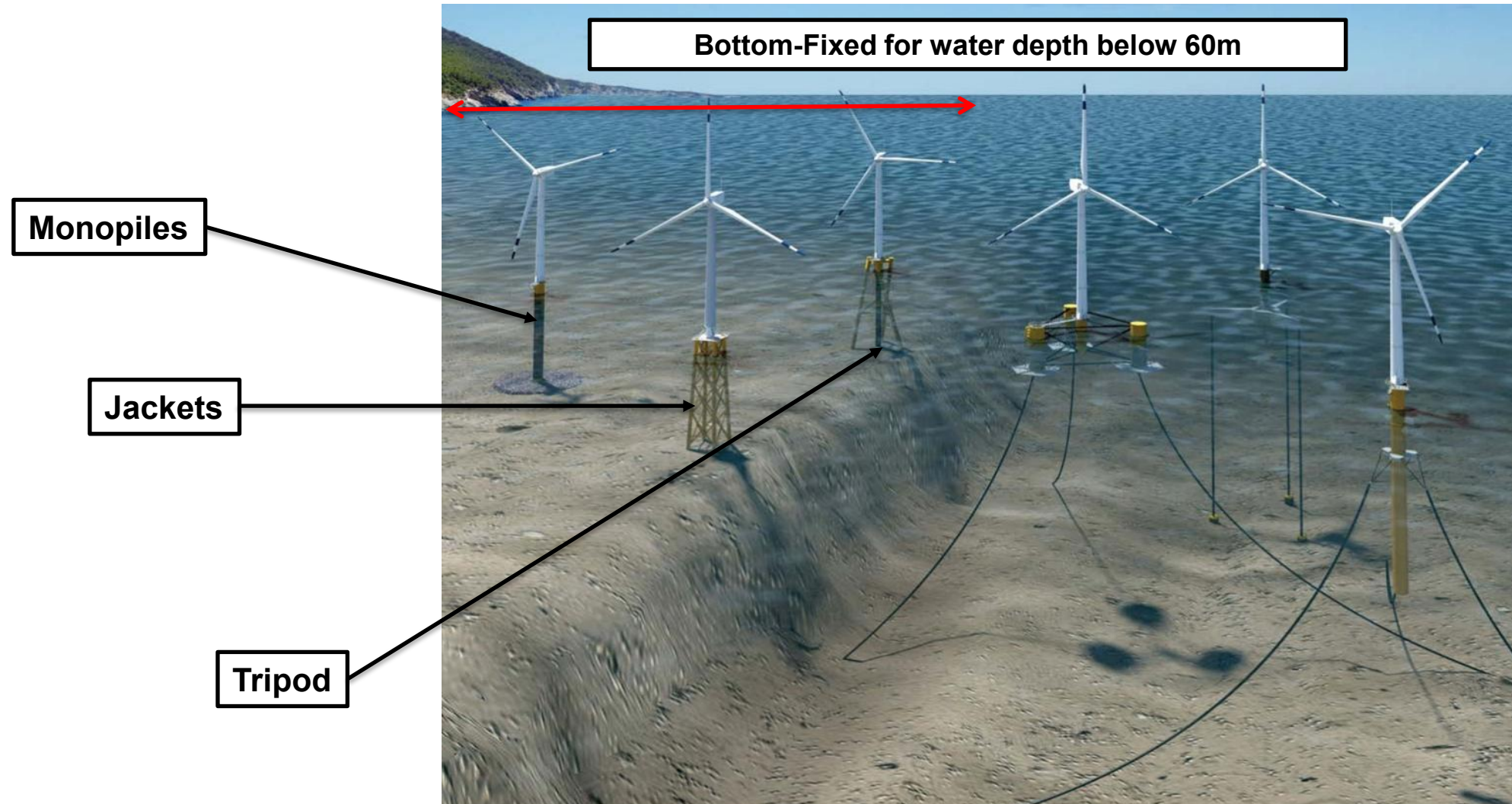
Offshore wind farm in 2013

Distance to shore : 100 km
Water depth : 50 m
Farm size : 340 MW
Wind turbine power : 7MW

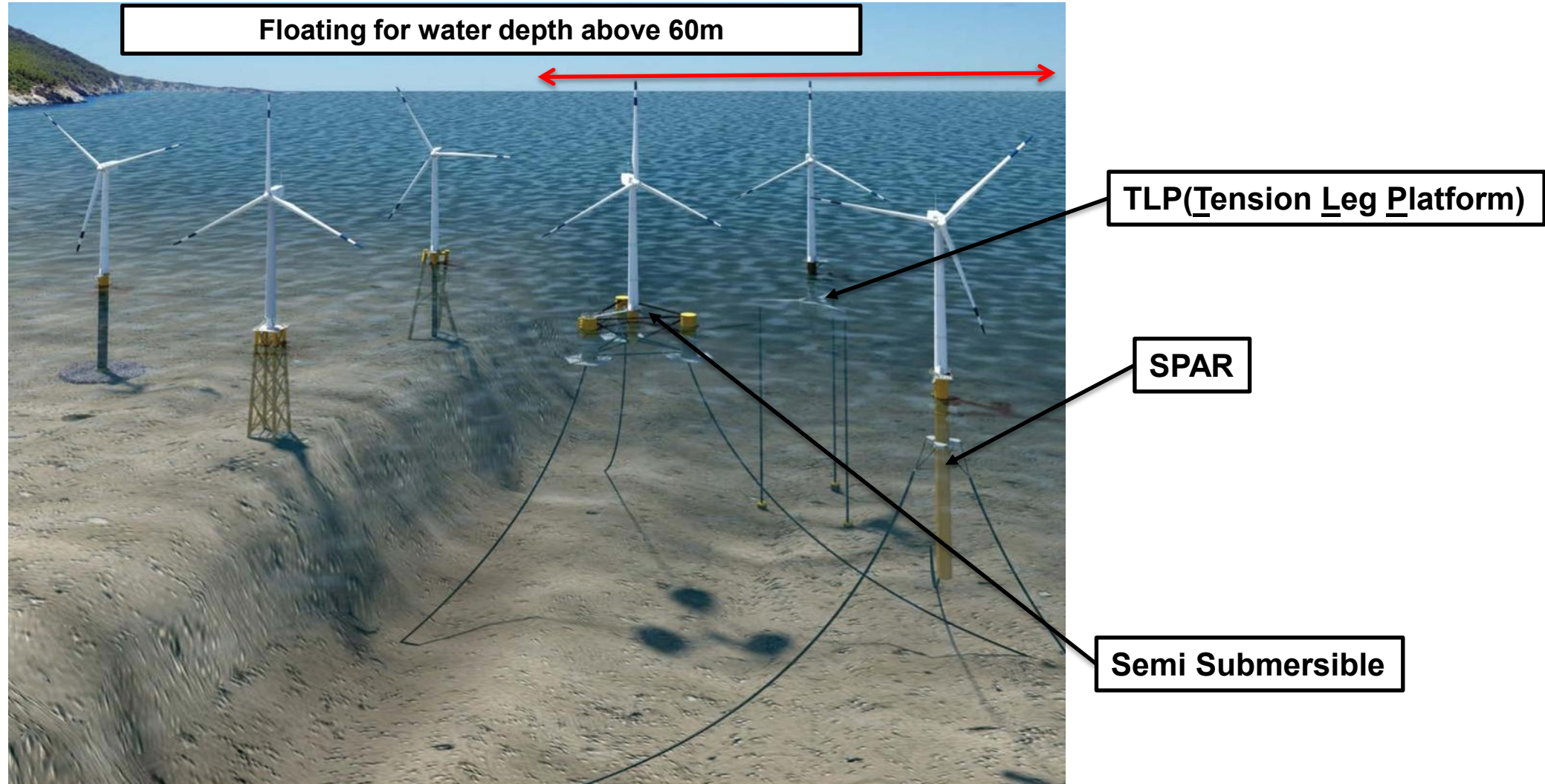
Offshore wind farm in 2022

Distance to shore : 150 km
Water depth : 70 m
Farm size : 1,200 MW
Wind turbine power : 14MW

Bottom Fixed Offshore Wind : the concept



F.O.W.F. (Floating Offshore Wind Farm) : the concept

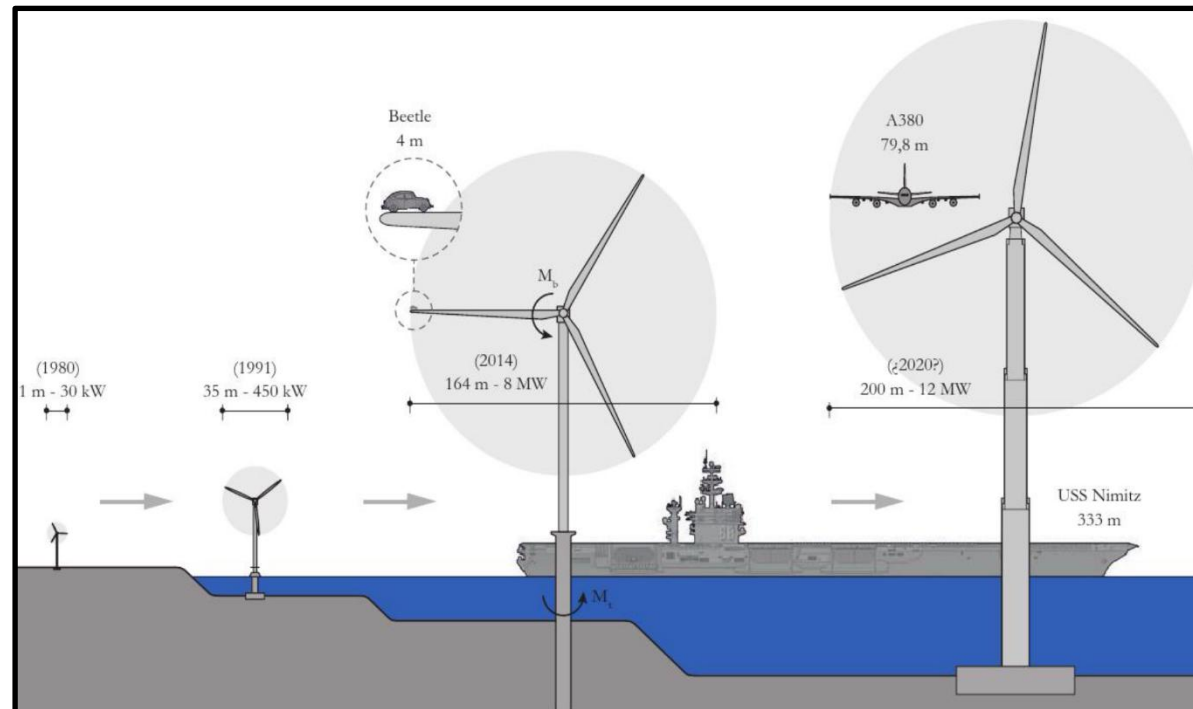


Bottom Fixed Offshore Wind : a mature industry



1981

Vindeby	
First offshore wind farm in the world	
	
5 MW	
Turbine capacity:	0.45 MW
Nr. of turbines	11
Rotor diameter	35 m
Distance to shore	1.8 km

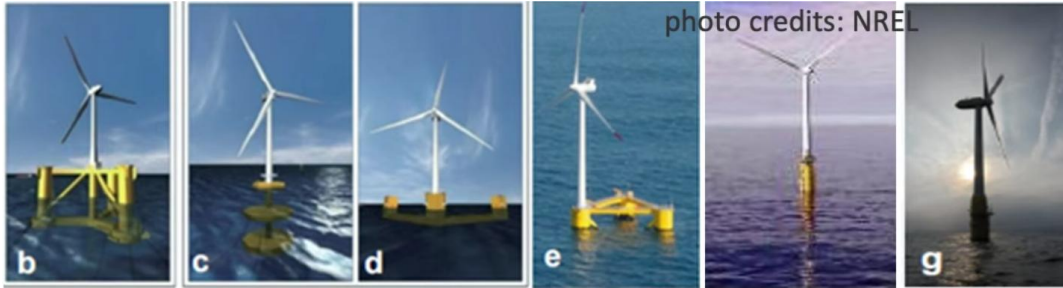


2022

Hornsea 2	
The world's largest offshore wind farm once constructed	
	
1,400 MW	
Turbine capacity:	8,5 MW
Nr. of turbines	165
Rotor diameter	170 m
Distance to shore	89 km



F.O.W.F. : new industry on path to commercialization



Proof of Concept Phase
2009 to 2016
Prototypes Ranging from 2 - 7 MW
Research Funded

Proof of Concept



Equinor Peterhead,
Scotland 30 MW 5
Turbines Øyvind Gravås /
Woldcam - Statoil ASA
(right)

PPI 25-MW Windfloat
Atlantic (left)



Pre-commercial Phase
2017 to 2023
Multi-turbine commercial machines
12 – 50 MW – financed with subsidies
14 projects totaling 229-MW

Pre-commercial



Figure credit: PPI

Utility-scale Floating Arrays
2024 and beyond
400-MW+ Capacity
Competitive with Market Conditions

Commercial



100+ concepts in development towards commercialization!!!

Technology				Technology readiness level (TRL)								
Concept	Designer	Material		1 Initial concept	2 Proof of concept	3 Numerical modelling	4 Tank testing	5 Scaled testing (<1MW)	6 1 - 5MW demo	7 > 5MW demo	8 Pilot (20 - 50MW)	9 Commercial project (>50MW)
Semi-Sub	WindFloat	Principle Power	Steel									2021
	OCG	Ocegy	Steel							2024		
	XCF	Mareal - Eiffage	Concrete								2025	
	OO-Star	Olav Olsen	Concrete							2023		
	Nautilus semi-sub	Nautilus - S7	Steel							2024		
	Tetrasub	Stiesdal	Steel									
	Trifloater	NOV-Gusto	Steel									
	Brunel	Fred Olsen	Steel									
	T-Floater	Bassoe - CIMC Raffles	Steel									
	w.semi	Wison	Steel									
TLP	NereWind	DORIS	Steel									
	TLP	SBM	Steel								2022	2025
	WindSub	Marine Power Systems	Steel						2023			
	FOWTLP	Bluewater	Steel									
	Gazelle	Gazelle	Steel									
	Modet TLP	Modet	Steel									
Spar	SOF	GICON	Steel									
	Hywind	Equinor	Both versions									2021
Barge	Crown	Seaplace	Concrete									
	Damping Pool	Ideol	Both versions						2018		2024	
	Swach	Sevan	Concrete									
Self-aligning platforms	Triwind	Beridi	Concrete									
	Sath	Saitec	Concrete					2020	2022		2025	
	Twin Wind	Hexicon	Steel					2018			2025	
	Nezzy?	EnBW-Aerodyn	Steel							2024		
	Eolink semi-sub	Eolink	Steel					2018		2023		
	PivotBuoy	X1 Wind	Steel					2021				
Counter-weight	W2Power	EnerOcean	Steel					2018				
	Tetraspar	Stiesdal	Steel						2021			
	Hexafloat	Saipem	Steel							2024		

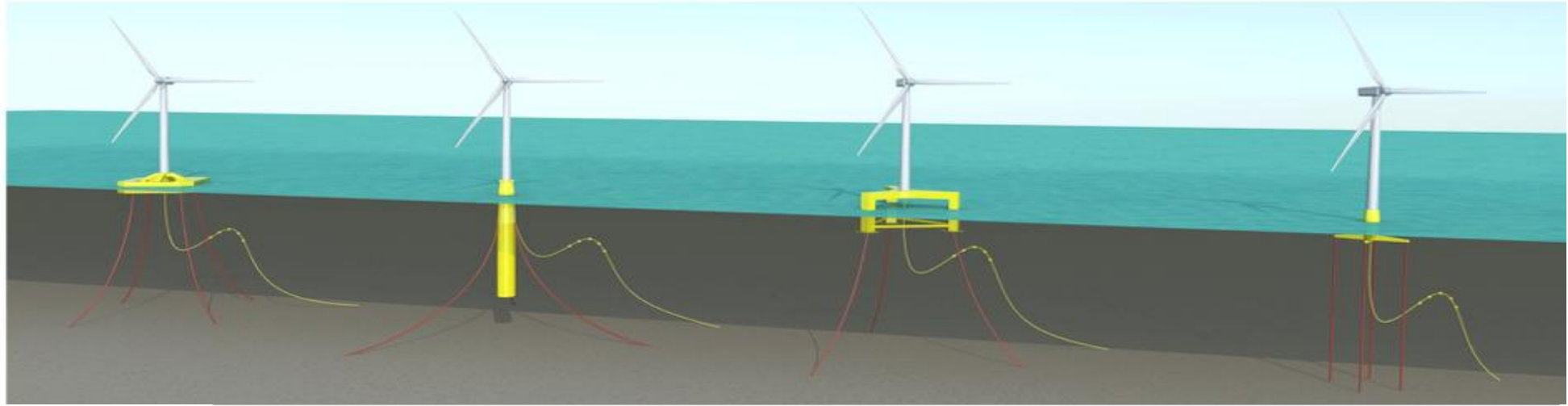


Source: The Carbon Trust, Shell analysis

Most active concepts, non-exhaustive



Various basic concepts



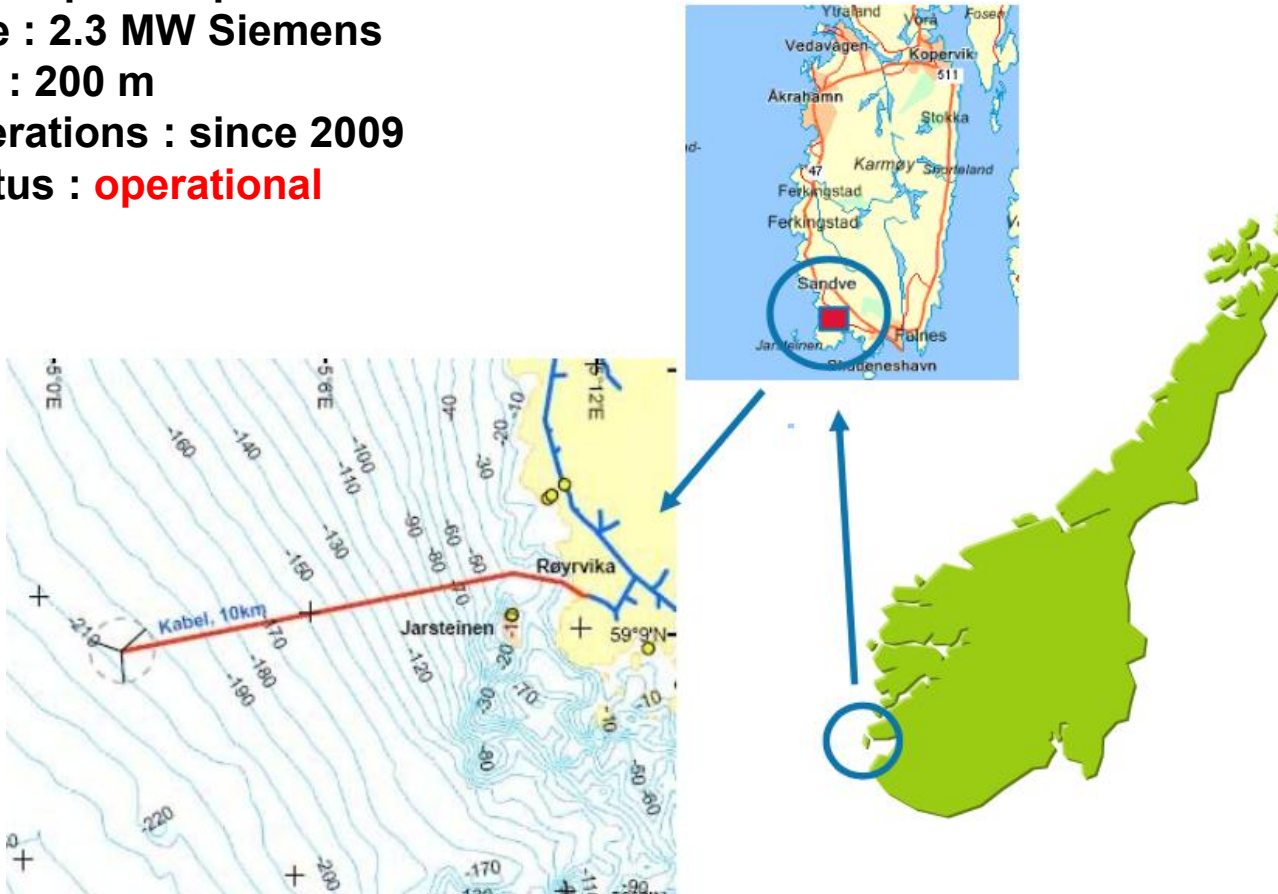
General Floater Archetype (15 – 20 MW)	Barge	Spar	Semi-Submersible	TLP
Outer Box Dimensions (L x B x H; excl. TP)	L: 55-65 m, B: 55-65 m H: 15-20 m	Ø: 20-25 m H: 100-140 m	L: 70-90 m, B: 80-100 m H: 35-40 m	L: 70-90 m, B: 80-100 m H: 35-55 m
Operational Draft	10 – 15 m	85 – 120 m	20 – 30 m	20 – 40 m
Port Assembly Draft (with tower & WTG)	5 – 10 m	85 – 120 m	5 – 20 m	5 – 10 m



Proof of concept : Equinor Hywind demo project

Concept : SPAR
Developer : Equinor
Size : 2.3 MW Siemens
WD : 200 m
Operations : since 2009
Status : **operational**

SPAR



Øyvind Hagen/Statoil



Proof of concept : BW Ideol Floatgen demo project

Concept : Barge damping pool

Developer : Ideol

Size : 2 MW Vestas

WD : 33m

Operations : since 2017

Status : **operational**

FLOATGEN, 1st floating wind demonstrator in France, installed in 2018

Objective: to validate the performance of the combination of a wind turbine and a floating foundation

Capacity: 2 MW (Vestas V-80)

Installation location: Le Croisic

Water depth: 33 m

Power generation: 6 GWh in 2019

Consortium:

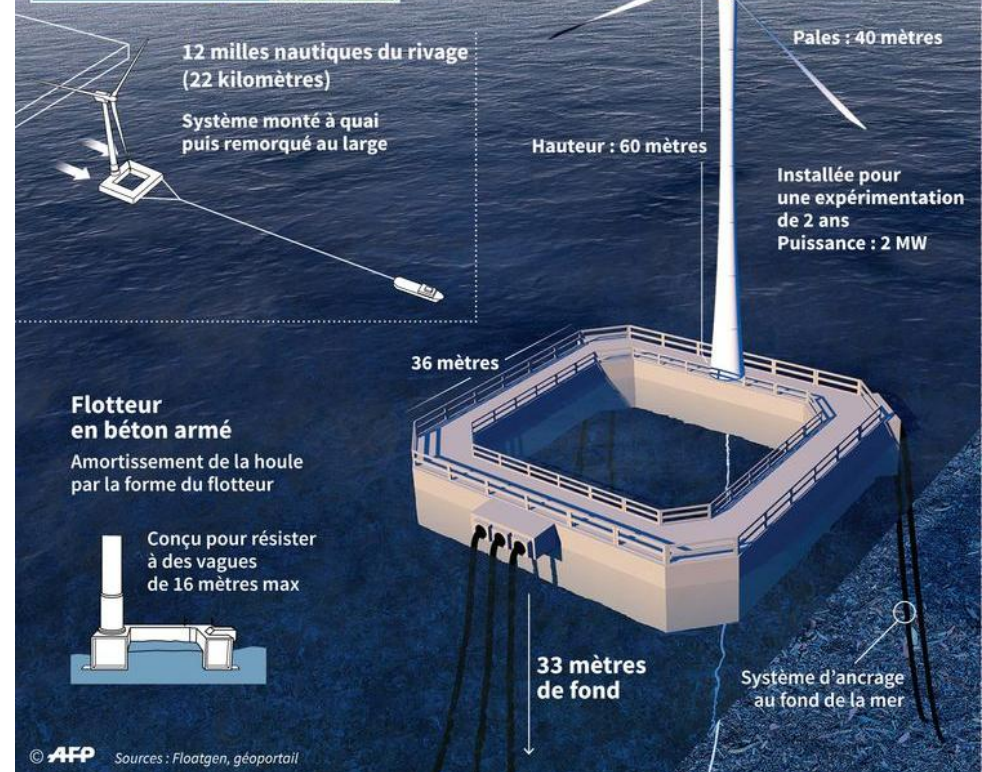


- 3 years + test
- Connected to the grid
- New concept : damping pool
- Floater in concrete / turbine support in steel
- Operational since 11/2017

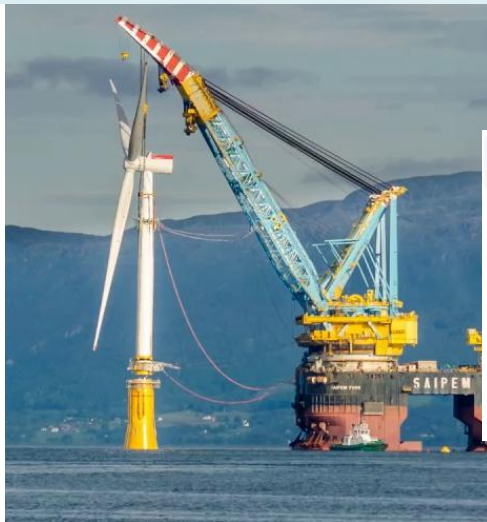
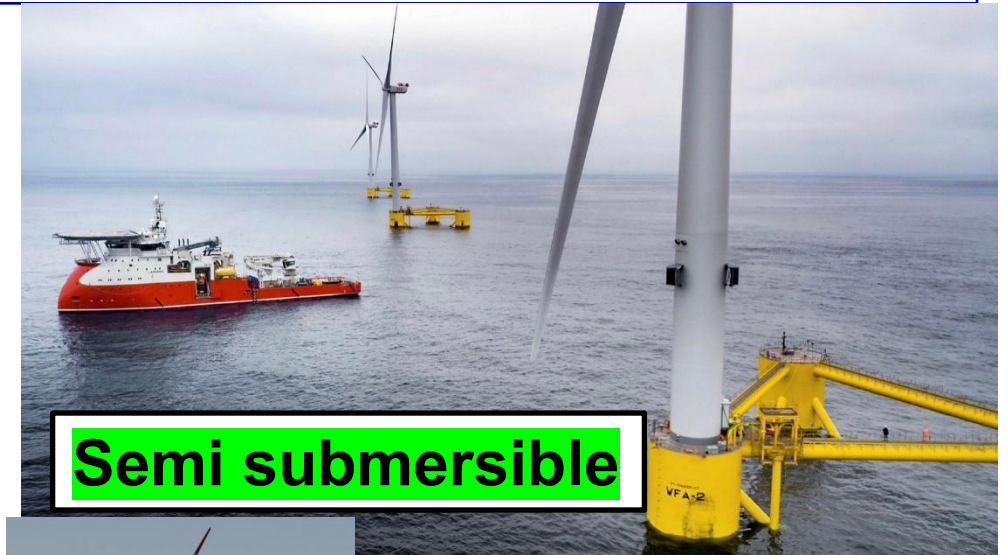
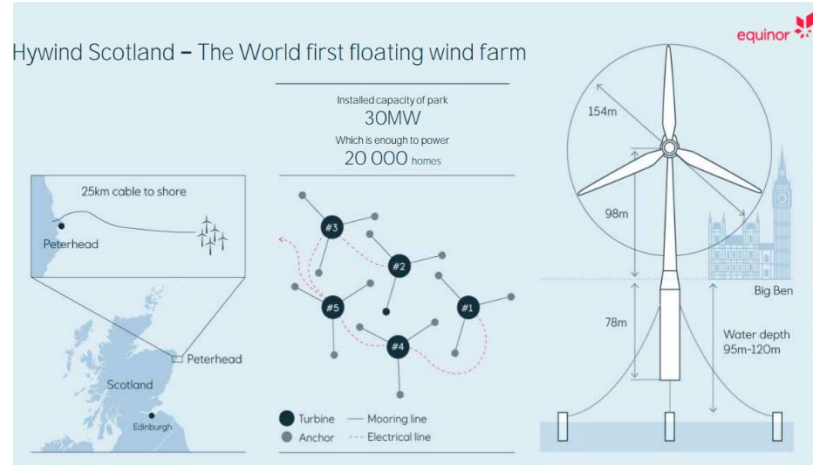
Première éolienne flottante installée en France



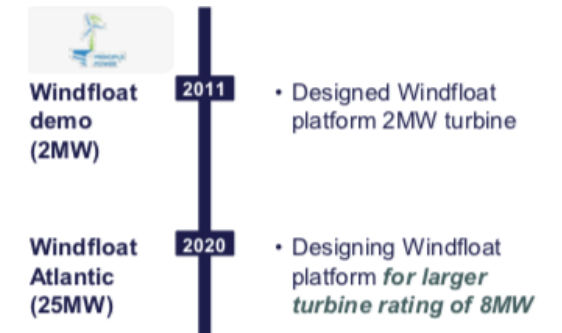
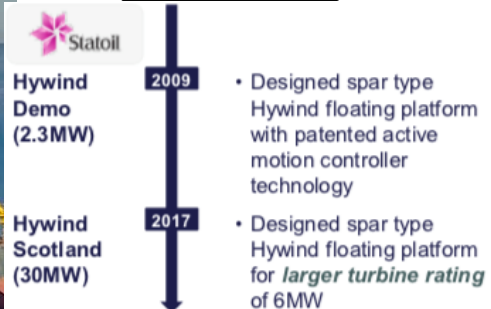
Barge



Pre-commercial : 2 proven concepts in operations



SPAR

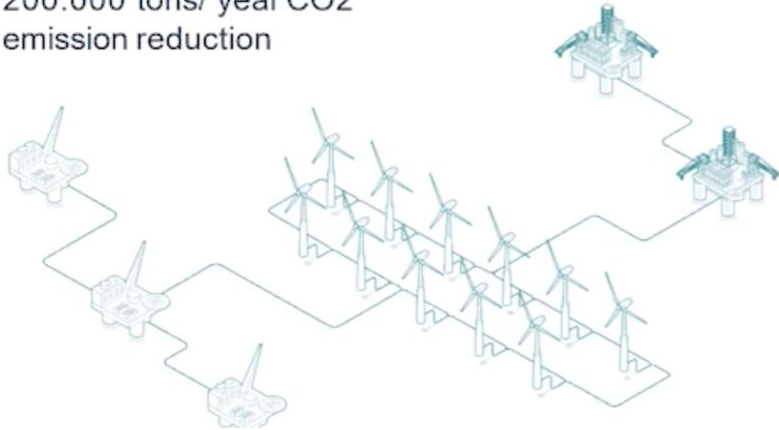


Pre-commercial : Equinor Hywind Tampen

Hywind Tampen

The world's first **floating** offshore wind farm to supply renewable power to offshore oil and gas installations.

- 11 wind turbines
- Combined capacity of 88MW
- Concrete substructures and shared anchors
- 200.000 tons/ year CO2 emission reduction

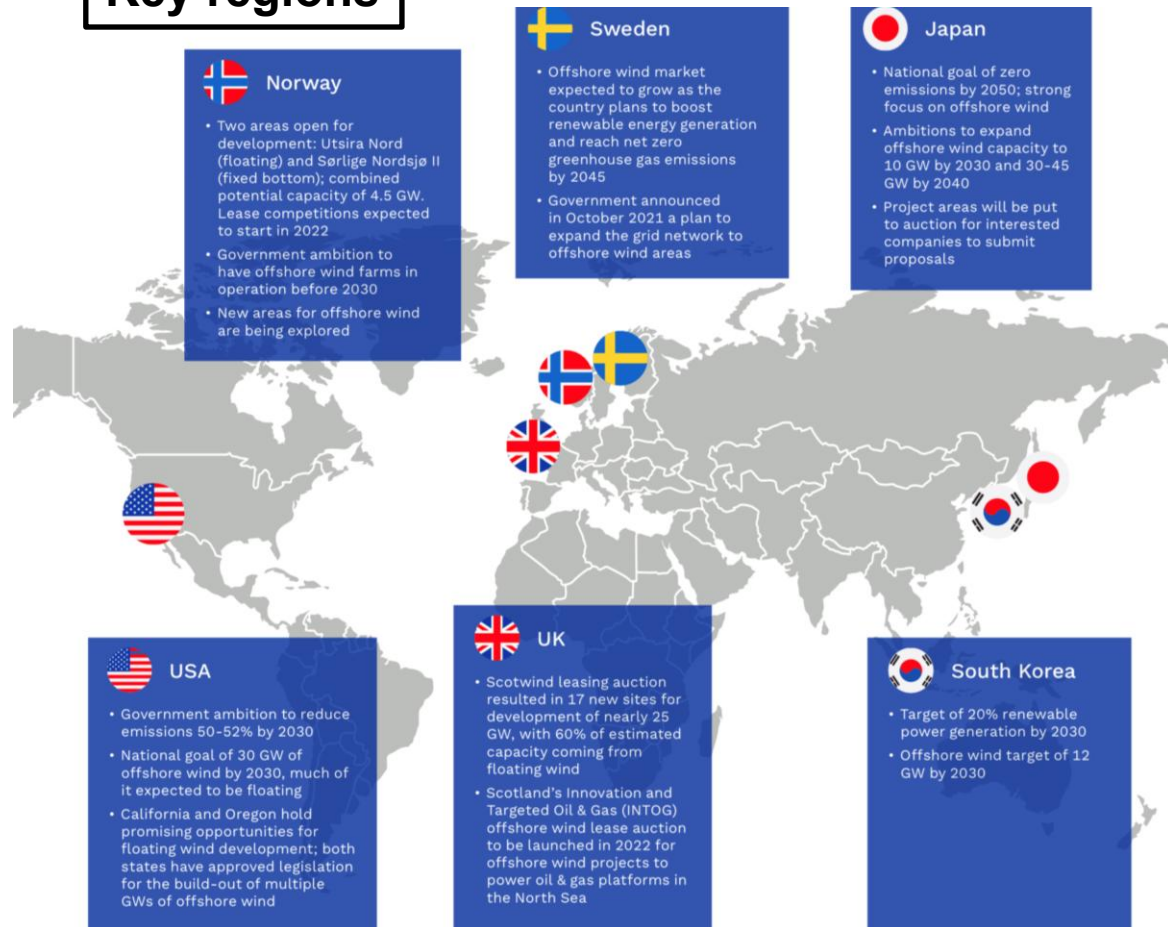


Decarbonising O&G platforms
Water Depth = 260 / 300m
11WTG x 8MW
550 M\$ CAPEX
Operational 2022



Commercial : floating array market

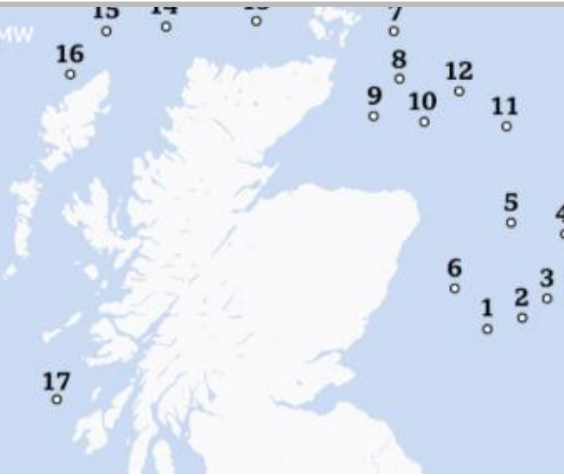
Key regions



Source Aker Offshore Wind

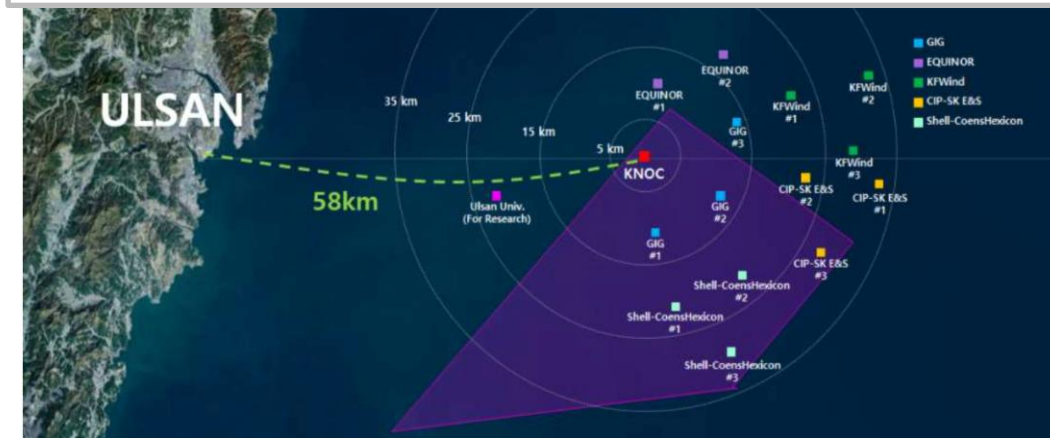
15GW of OWF floating awarded in 1/2022

1 BP Alternative Energy Investments 2,907MW
 2 SSE Renewables 2,610MW
 3 Falck Renewables 1,200MW
 4 Shell New Energies 2,000MW
 5 Vattenfall 798MW
 6 DEME 1,008MW
 7 DEME 1,008MW
 8 Falck Renewables 1,000MW
 9 Ocean Winds 1,000MW
 10 Falck Renewables 500MW
 11 Scottish Power Renewables 3,000MW
 12 BayWa 960MW
 13 Equinor 2,000MW
 14 Equinor 1,500MW
 15 Northland Power 840MW
 16 Northland Power 840MW
 17 Scottish Power Renewables 2,000MW



Key prospects

5 GW of OWF floating with COD scheduled in 2026



Wind offshore – New ideas.....



Source: Wind Catching Systems (Norway)

250

TPA Toolbox Energy Book 7 – Renewables

The Wind Energy Programme & PPE in France

See also Book 2 Energy – Chapter 5



SYNTHÈSE

STRATÉGIE FRANÇAISE POUR
L'ÉNERGIE ET LE CLIMAT

PROGRAMMATION PLURIANNUELLE DE L'ÉNERGIE

2019-2023

2024-2028



Source: Ministère de la Transition Ecologique et Solidaire



Reminder PPE : Ceiling Prices for future Call for Tenders Prices are declining

Date d'attribution de l'AO	2019	2020	2021	2022	2023	>2024
Eolien flottant			250 MW <i>Bretagne Sud</i> (120 €/MWh)	2 x 250 MW <i>Méditerranée</i> (110 €/MWh)		1 000 MW par an, posé et/ou flottant, selon les prix et le gisement, avec des tarifs cibles convergeant vers les prix de marché sur le posé
Eolien posé	600 MW <i>Dunkerque</i> (45 €/MWh)	1 000 MW <i>Manche Est</i> <i>Mer du Nord</i> (60 €/MWh)*	500 – 1 000 MW <i>Sud-Atlantique**</i> (60 €/MWh)		1 000 MW (50 €/MWh)	

* Pour ce projet, la date de 2020 est la date de lancement de la procédure de mise en concurrence.

** Dans ce cadre, un projet éolien en mer au large d'Oléron pourrait être attribué.

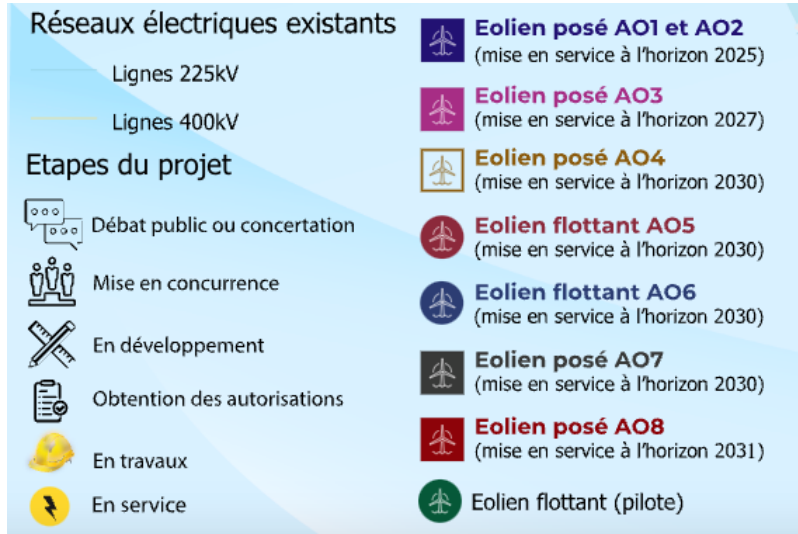
Les dates indiquées sont les dates auxquelles un lauréat sera sélectionné, en fin de procédure de dialogue concurrentiel ; les prix indiqués sont les prix cibles des appels d'offres sur la base desquels seront fixés les prix plafonds des appels d'offres. Les projets attribués à partir de 2024 portent notamment sur des extensions des parcs éoliens en mer précédents, avec un raccordement mutualisé.

Source: Ministère de la Transition Ecologique et Solidaire
Eolien en mer et Énergies renouvelables électriques – Août 2021

253



Offshore wind projects status in France (end 2022)



- **PRODUCING :**
 - 1 floating **proof of concept** project (IDEOL 12/2017)
 - 1 bottom fixed **commercial** project (Saint-Nazaire 12/2022)
- **UNDER CONSTRUCTION :**
 - 6 bottom fixed **commercial** projects
 - 3 floating **pre commercial** projects
- **UNDER TENDER :**
 - 3 bottom fixed **commercial** projects
 - 2 floating **commercial** projects

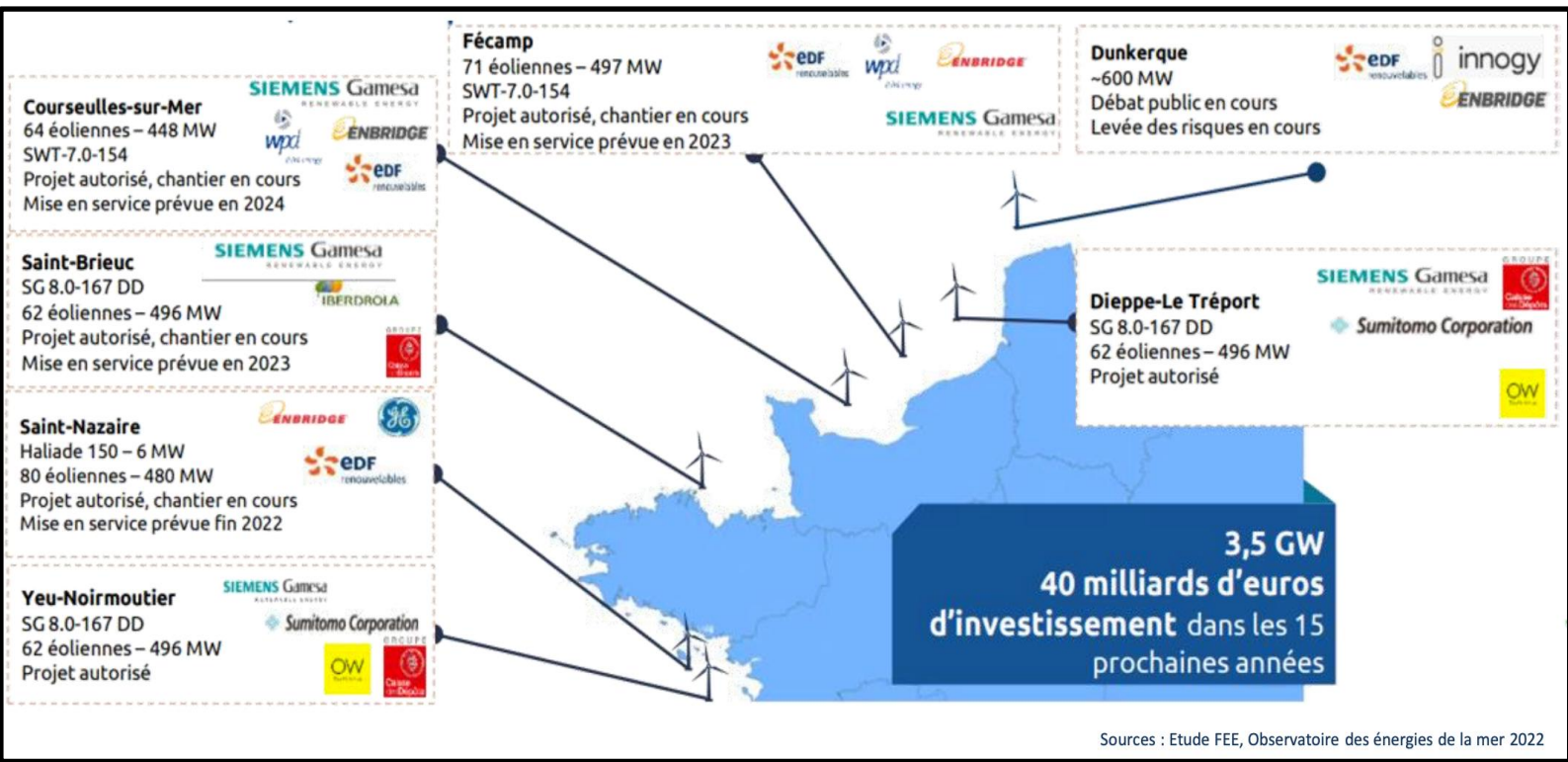
AO1-AO3 : 6 bottom-fixed commercial projects under construction



Eolien posé AO1 et AO2
(mise en service à l'horizon 2025)



Eolien posé AO3
(mise en service à l'horizon 2027)



Sources : Etude FEE, Observatoire des énergies de la mer 2022

Parc éolien	État actuel	Date prévisionnelle de mise en service
Banc de Guérande – Saint-Nazaire	Travaux	Fin 2022
Baie de Saint-Brieuc	Travaux	Fin 2023
Hautes falaises – Fécamp	Travaux	Fin 2023
Calvados – Courseulles-sur-mer	Travaux	2024
Dieppe – Le Tréport	Développement	2026
Les deux Îles – Yeu – Noirmoutier	Développement	2026
Dunkerque	Études et préparation du dossier de demande d'autorisations	2027

Each circa : 500MW size / 2B€ Capex



5 ongoing tenders : Appel d'offres (AO4 to AO8) as of 4/2023

	Technology	Capacity	Location
AO4	Bottom fixed	1000 MW	Normandy
AO5	Floating	250 MW	South Brittany
AO6	Floating	2 x 250 MW	Mediterranean sea
AO7	Bottom fixed	500 à 1000 MW	South Atlantic
AO8	Bottom fixed	1000 MW	To be confirmed

Competitive landscape fixed AO6

1. [BlueFloat Energy](#), [Sumitomo Corporation](#) & [Akuo Energy](#)
2. [Eolienne Occitanie Grand Large](#) & [Eolienne Méditerranée Grand Large](#) ([EDF](#)+[Maple Power](#)+[BW Ideol](#))
3. [BayWa r.e.](#) & [Elicio](#)
4. [Océole](#) + [Qenergy](#) + [Equinor](#) + green [Giraffe](#)
5. [Iberdola](#)
6. [OceanWinds](#) associé à la Banque des Territoires
7. [RWE-BOURBON](#)
8. Les Moulins du [leonis](#) ([Shell](#)+[ENBW](#))
9. Archipel Energie Marine ([Qair](#)+[TotalEnergies](#)[Corio Generation](#))
10. [WPD](#) now [Skyborn Renewables](#)
11. [Vattenfall](#)
12. [Cobra Instalaciones y Servicios S.A.](#)

AO4 : award to EDF (4/2023)

Competitive landscape floating AO5

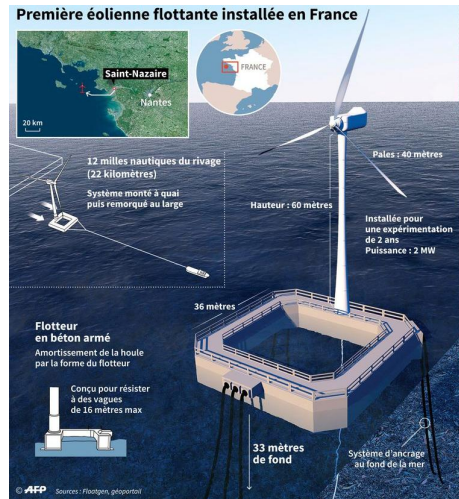
 	  	
	  	
 	 	
	 	

Competitive landscape fixed AO8

- Alliance formée par [Vattenfall](#), [Skyborn Renewables](#) et la Banque des Territoires
- Groupement Eoliennes en Mer du Suroit ([EDF](#) [Renouvelables](#) et [Maple Power](#))
- [Ocean Winds](#)
- Groupement Cotentin Energies Marines ([TotalEnergies](#) et [RWE](#))
- [Iberdrola](#)
- Groupement Energies du Méridien ([Corio Generation](#) et [Qair Eolien Posé Manche](#))
- [Eni Plenitude](#)



1 proof of concept project in ops – 3 pre-commercial projects under construction

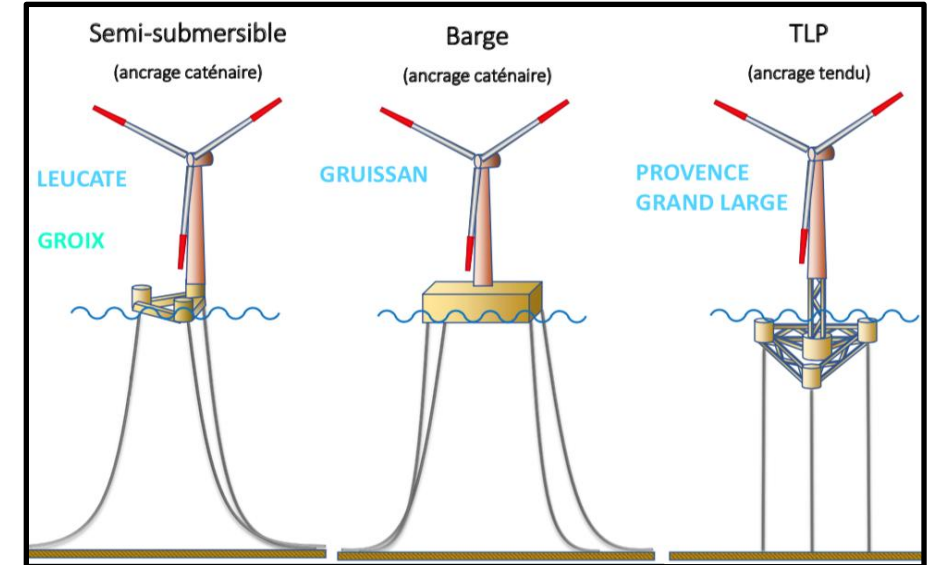


Proof of concept (Installed Q4 2017)

FLOATGEN, 1st Floating wind demonstrator in France, installed in 2018
Objective: to validate the performance of the combination of a wind turbine and a floating foundation
Capacity: 2 MW (Vestas V-80)
Installation location: Le Croix
Water depth: 33 m
Power generation: 6 GWh in 2019
Consortium:



- **Concept/Developer :** initially 4 & now 3 after **Shell decision to withdraw from Groix- Belle Ile project**
- **CAPEX :** 200M€
- **Size :** 30MW
- **WD :** 70-100m
- **Operations :** starting 2022/23
- **Status :** **under construction**



Project	Characteristics	Industrial partners
Provence Grand Large	3 turbines – 24 MW	EDF, OFFSHORE, SIEMENS Gamesa
Groix-Belle Île	3 turbines – 28.5 MW	CGN, VINCI, NAVAL ENERGIES, MIV
Eolmed	3 turbines – 30 MW	Qair, Ideol, MIV
EFGL (Floating Offshore of Golfe du Lion)	3 turbines – 30 MW	OW, FIFFAGE, MIV



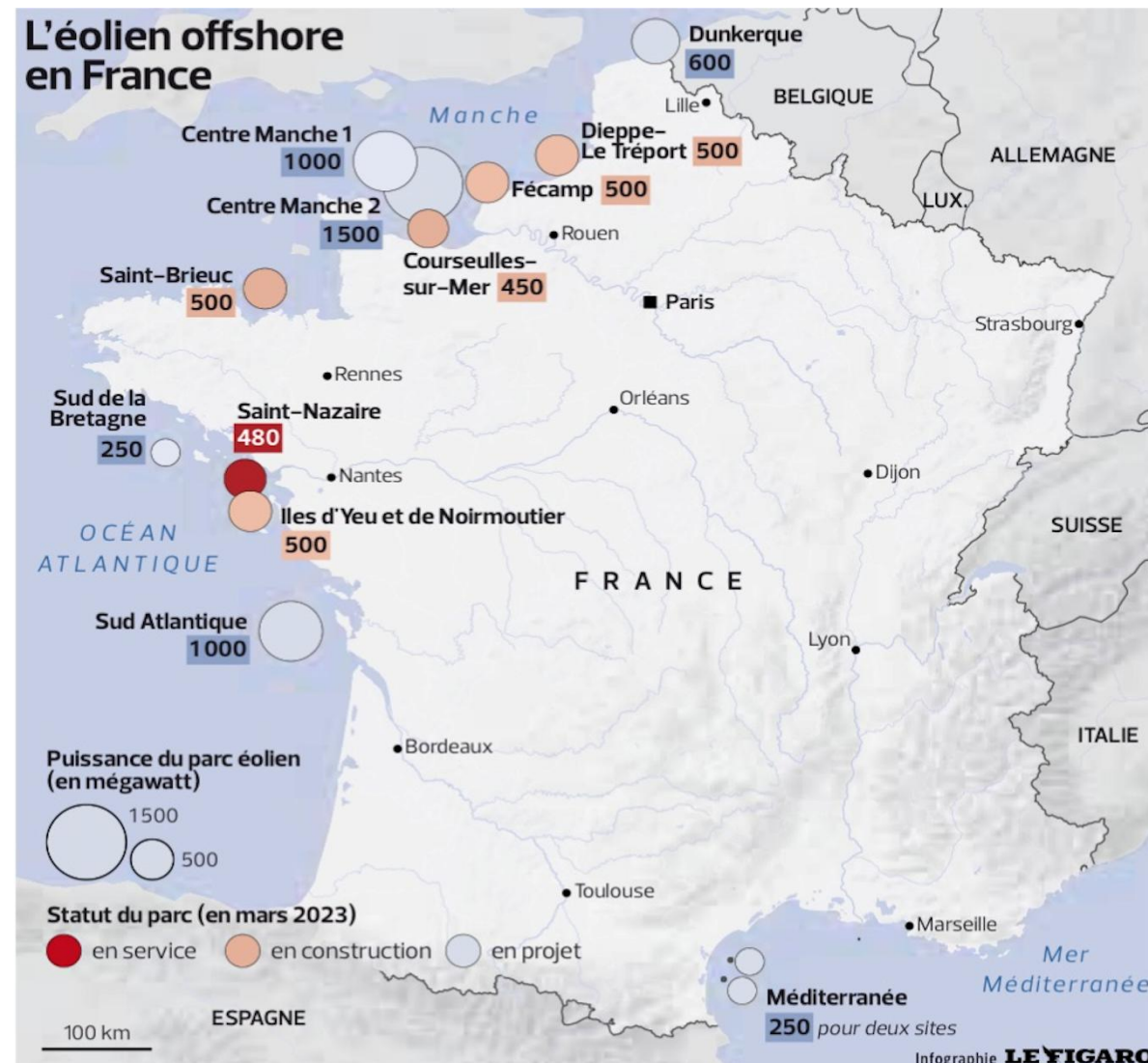
Offshore wind farms status early 2022

Parc	Puissance (MW)	État	Début des travaux	Mise en service	Fondation	Nombre d'éoliennes	Distance des côtes (km)	Superficie (km²)
Dunkerque	600	Attente	2025	2027	Monopieu	46	10	50
Dieppe - Le Tréport	496	Attente	2024	2026	Jacket	62	15,5	110
Centre Manche I	1000	Projet	Inconnu	2028	Posé	Inconnu	32	300
Centre Manche II	1500	Projet	Inconnu	2031	Posé	75 à 125	45	220 à 250
Fécamp	498	Chantier	2020	2023	Gravitaire	71	13	60
Calvados	450	Chantier	2021	2024	Monopieu	64	10	54
Saint-Brieuc	496	Chantier	2021	2023	Jacket	62	16,3	75
Groix - Belle-Île (pilote)	28	Projet	2019	2022	Flottant	3	13	14
Bretagne Sud	250	Projet	Inconnu	2029	Flottant	Inconnu	Inconnu	50
Bretagne Sud (extension)	500	Projet	Inconnu	Inconnu	Flottant	Inconnu	Inconnu	Inconnu
Saint Nazaire	480	Chantier	2019	2022	Monopieu	80	12	78
Yeu - Noirmoutier	496	Attente	Inconnu	2025	Monopieu	62	11,7	83
Sud Atlantique	500 à 1000	Projet	2025	2030	Posé	33 à 66	10 à 30	60 à 180
Sud Atlantique (extension)	1000	Projet	Inconnu	Inconnu	Posé	Inconnu	Inconnu	Inconnu
Gruissan (pilote)	30	Attente	2022	2023	Flottant	3	18	8,15
Leucate (pilote)	30	Attente	2022	2023	Flottant	3	16	6,17
Faraman (pilote)	25	Attente	2022	2023	Flottant	3	17	0,78
Méditerranée I	250	Projet	2027	2029	Flottant	20	Inconnu	100 à 200
Méditerranée I (extension)	500	Projet	Inconnu	Inconnu	Flottant	Inconnu	Inconnu	Inconnu
Méditerranée II	250	Projet	2027	2029	Flottant	20	Inconnu	100 à 200
Méditerranée II (extension)	500	Projet	Inconnu	Inconnu	Flottant	Inconnu	Inconnu	Inconnu



Offshore wind farms status : target for COD

Project	MW	Techno	Target CoD
Le Croisic	2	Floating	2018
Saint-Nazaire	480	Fixed	2022
Fécamp	498	Fixed	2023
Saint-Brieuc	496	Fixed	2023
Couseulles	450	Fixed	2023
Tréport	496	Fixed	2024
Noirmoutier	496	Fixed	2025
Dunkerque	496	Fixed	2026
Provence GL	24	Floating	2022
Eolmed	30	Floating	2023
Golfe du Lion	24	Floating	2023
Groix	24	Floating	2022



3 main manufacturing sites in France



Turbines assembly – Saint-Nazaire – General Electric



Blade's factory – Cherbourg – LM Wind Power



© Siemens Gamesa Renewable Energy S.A

SIEMENS Gamesa
RENEWABLE ENERGY

Blades and turbines factory – Le Havre – Siemens Gamesa Renewable Energy



Harbours development

- Un Grand Ouest avec une offre structurée en réseau pour répondre aux enjeux industriels et portuaires pour l'éolien flottant



TERMINAL EMR BREST

- 40 ha
- 400 m quai charge lourde
- Compétences Navale



LORIENT

- Terre-pleins pour le stockage et la maintenance d'équipements
- Offre de service diversifiée



NANTES ST.NAZAIRE

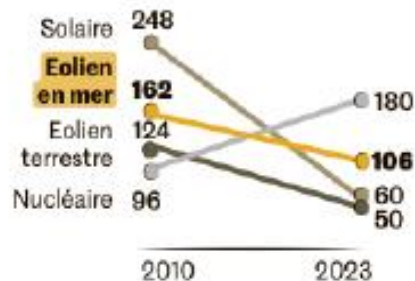
- Grand Port Maritime
- 12 ha Hub d'assemblage à St.Nazaire
- Usines Chantiers de l'Atlantique, GE



Wind Offshore overview France

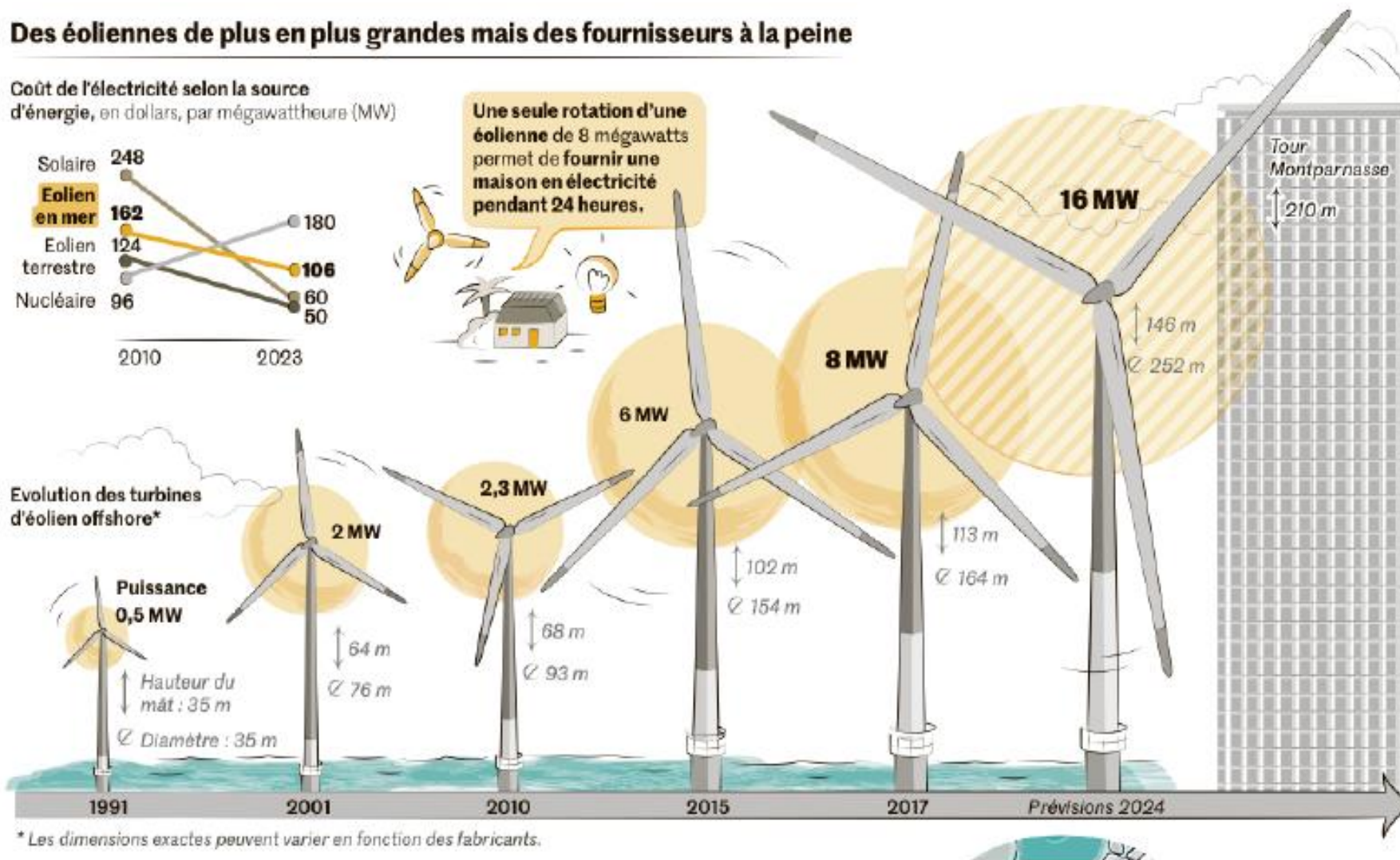
Des éoliennes de plus en plus grandes mais des fournisseurs à la peine

Coût de l'électricité selon la source d'énergie, en dollars, par mégawattheure (MW)



Une seule rotation d'une éolienne de 8 mégawatts permet de fournir une maison en électricité pendant 24 heures.

Evolution des turbines d'éolien offshore*



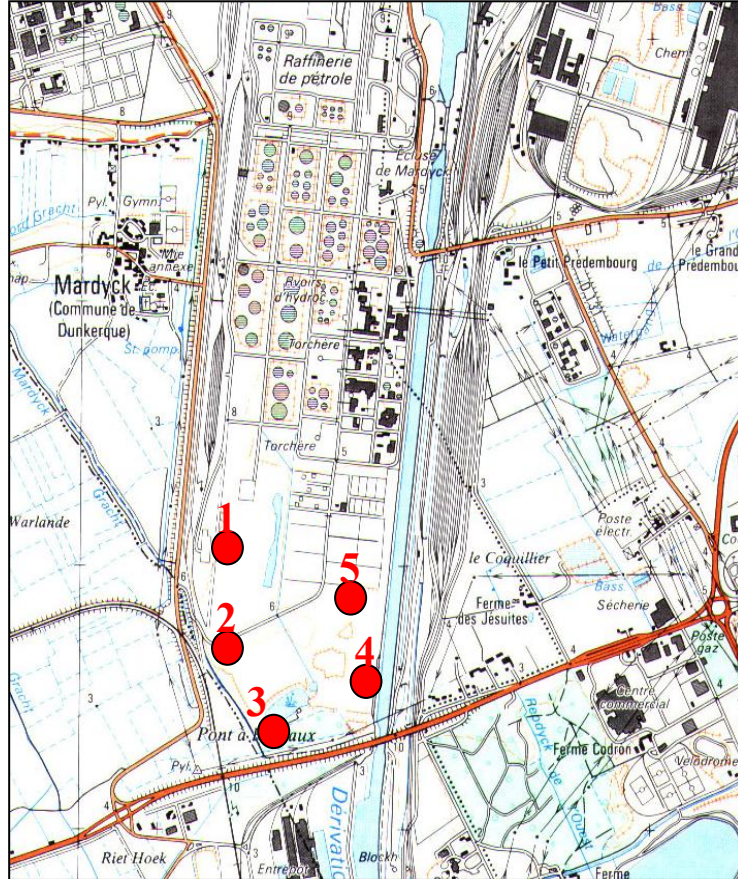
* Les dimensions exactes peuvent varier en fonction des fabricants.

2-4

Wind Energy, the approach of TotalEnergies



2003 Mardyck: a demonstration project, located close to a Total refinery



- ◆ 5 multi-megawatt wind turbines from 3 Manufacturers
- ◆ 12 MW installed capacity, which represents the domestic consumption of 15.000 people
- ◆ a land leased for 25 years
- ◆ commissioned in November 2003



Manufacturer	GE WIND	NORDEX	VESTAS
Nb	1 Prototype	2	2
Country	Germany	Denmark	Denmark
Type	GE Wind 3.2	N80	V80
Nominal Power	3 000 kW	2 500 kW	2 000 kW
Certification	Class 2	Class 2	Class 2
Rotor axis	Horizontal	Horizontal	Horizontal
Yaw	Upwind	Upwind	Upwind
Tower height	95 m	80 m	80 m
Rotor diameter (3 blades)	104 m	80 m	80 m
Rotor speed (rpm)	Variable, 7,5 to 13,5	Variable, 10 to 19	Variable, 10 to 19
Nominal wind speed	13 m/s	14 m/s	14 m/s
Startup wind speed	4 m/s	4 m/s	4 m/s
Shutdown wind speed	25 m/s	25 m/s	25 m/s
Equipment Control	Pitch control	Pitch control	Pitch control



2017 Acquisition of EREN by Total

**Total partners with EREN Renewable Energy
to expand Its Renewable Business**

Transaction Value = 237,5 M€

23% of EREN RE

EREN RE Activity:

Renewable Electricity Production:

Wind Energy, Solar Energy, Hydroelectricity



2019 TotalEnergies entering the Wind market

TOTAL INTEGRATES CLIMATE CHALLENGES IN ITS STRATEGY

Expand our presence across the entire natural gas chain

Develop a profitable low-carbon electricity business

Focus on low-breakeven oil projects

Invest in carbon neutrality businesses

Historical players / First movers

Ørsted

- Pure Player
- **Maintaining leadership**
- Expansion in the USA and Asia

RWE
e-on 

- 2nd worldwide operator after Asset Exchanges
- **Global expansion**

VATTENFALL 

- Focusing on Northern Europe and France
- **Present on downstream**

Utilities challenging historical players

 **IBERDROLA**

 **sse**

EnBW

 **edf**

 **ENGIE**

Oil & Gas entering the business

 **equinor**

- Focusing on offshore wind energy
- **Leader on the floating subsector**
- **Integration in the electricity value chain**



TotalEnergies Energy Outlook 2022

two scenarios:

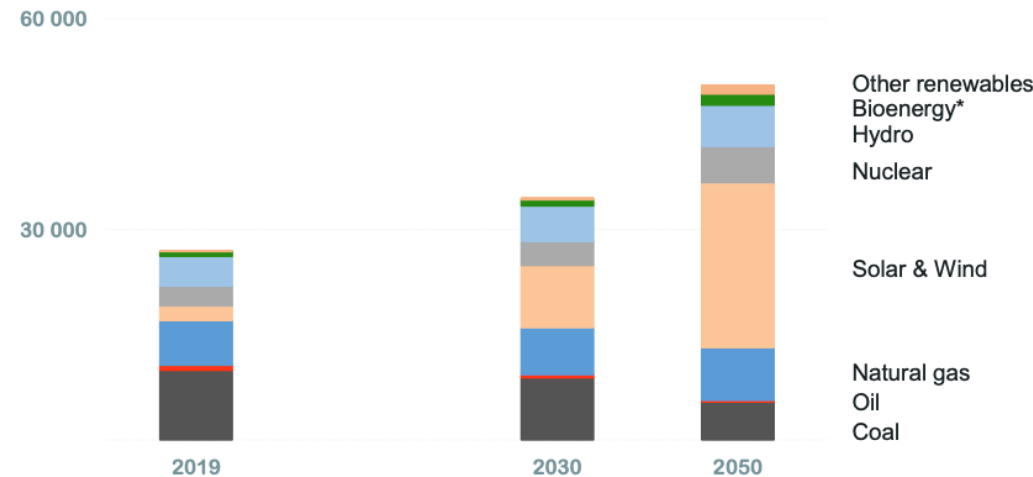
MOMENTUM

Based on current trends

RUPTURE

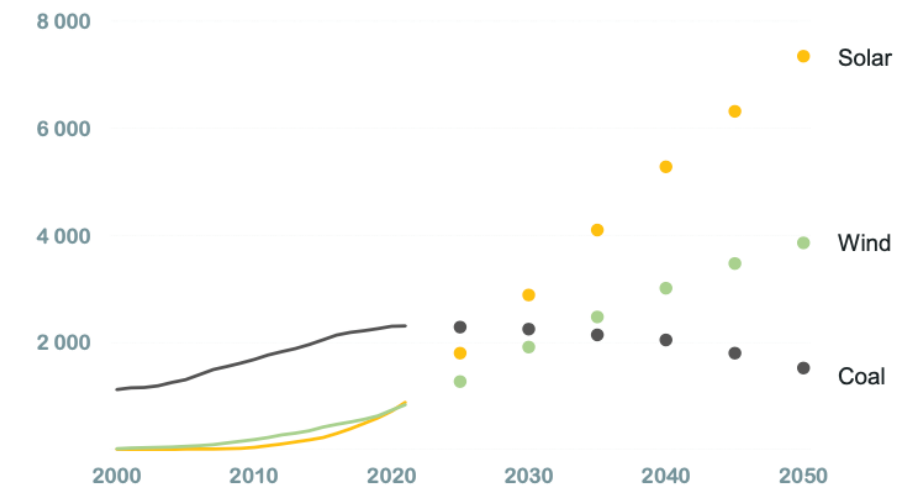
Requires disruptive technological or regulatory changes

Power generation, excluding power for Green H₂ (Momentum)
TWh



- Power demand and generation almost doubling by 2050 (+2% p.a.), with wind & solar representing ~90% of new generation
- Huge decrease of coal-fired generation, complete phase-out in NZ countries
- Despite strong gas-to-REN switch, gas grows in absolute terms to manage variability of solar & wind and demand seasonality
- Renewed investment in nuclear

Power capacities, excluding for Green H₂ (Momentum)
GW

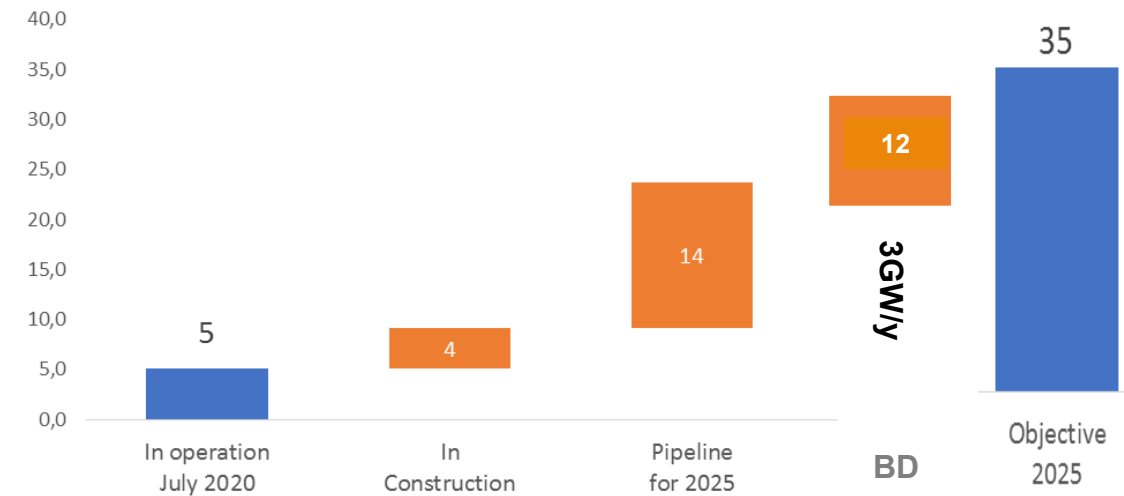


- Solar & wind capacities multiplied by ~7 in 30 years, representing 60% of all power capacities in 2050
- Coal capacities starting to decrease in the late 20's
- Average power emission factor reduced by ~75% by 2050 (net of CCS)

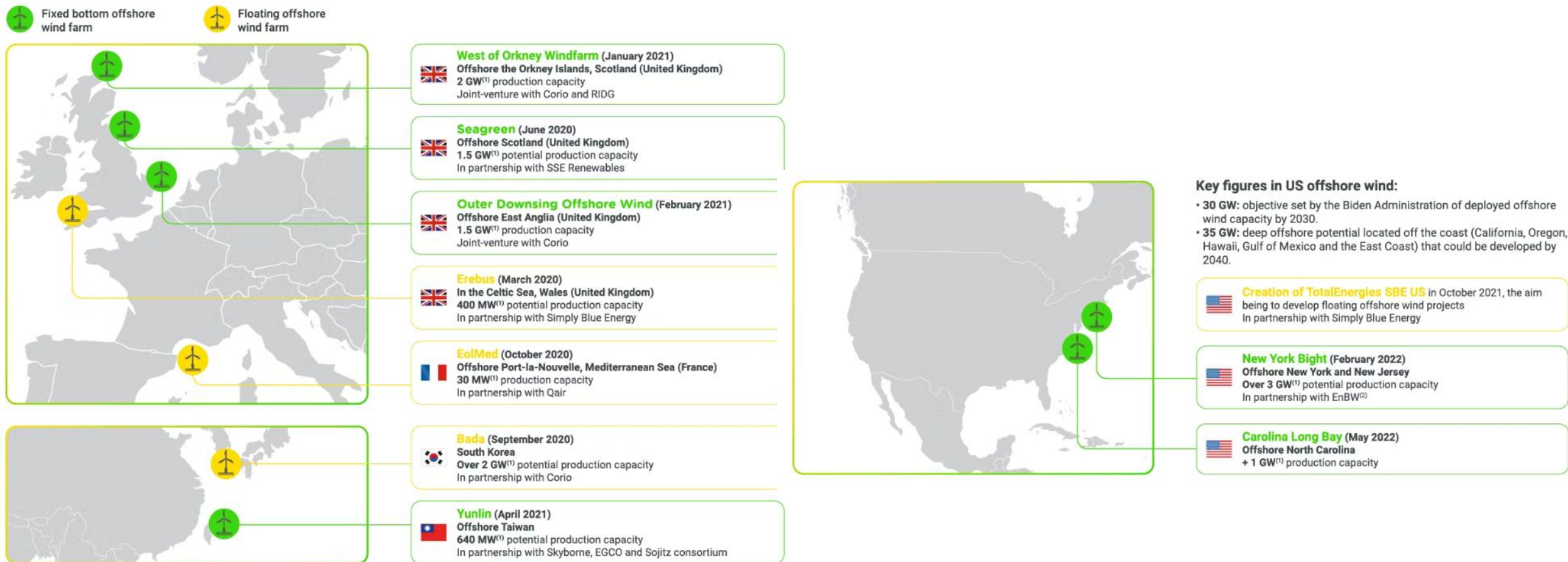
Source : TotalEnergies Energy Outlook Scenarios 2022



2025 Objective : 35 GW gross capacity installed



TotalEnergies overall OWF(Offshore Wind Farm) portfolio (end of 2022)



Source : TotalEnergies Shareholders' Newsletter Fall 2022



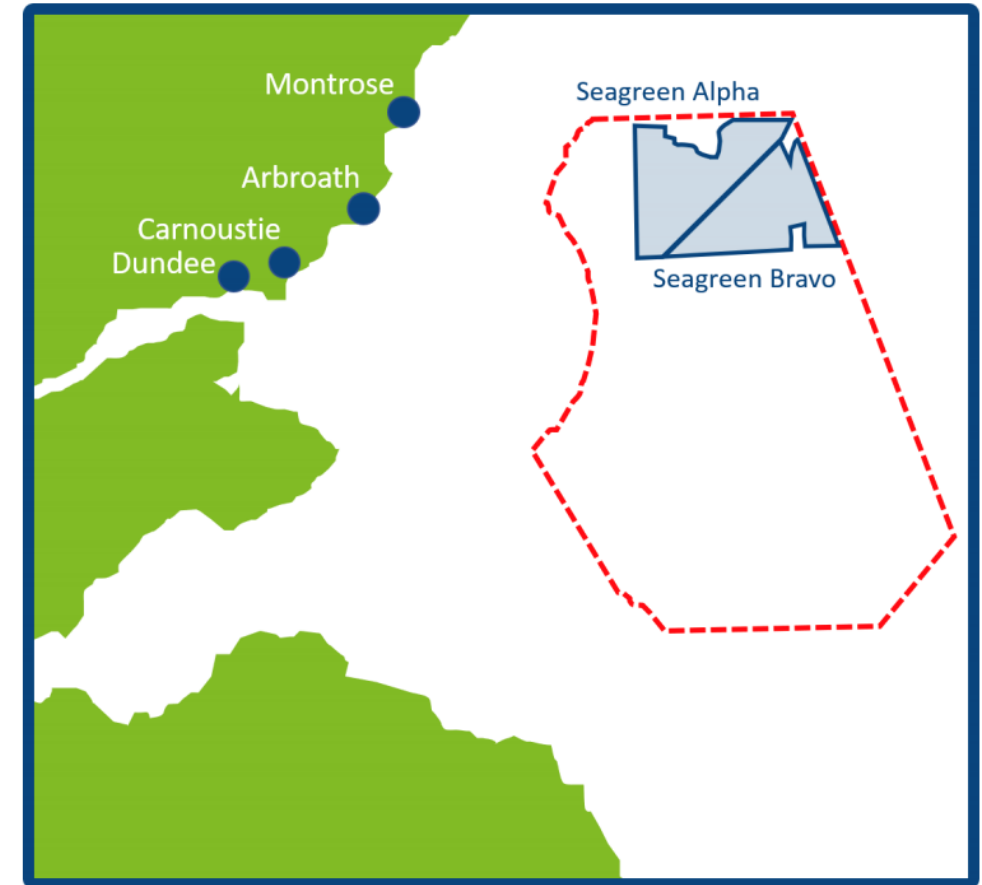
Ongoing Offshore Wind Project with TotalEnergies partner

Seagreen (UK) 1.1 GW	Largest Scotland offshore wind project 3.7 B\$ project	51% Total / 49 % SSE ~ 70% gearing >70% covered by PPA
Eolmed (Fr) 30 MW	Floating offshore wind pilot	20% Total / 70 % Qair EPC tender in progress
Erebus (UK) 100 MW	First commercial Floating offshore wind	80% Total / 20 % SBE Design in progress
Bada (South Korea) >2 GW	Large scale Floating offshore wind	50% Total / 50 % Green Investment Group Korea Feeding post 2025 growth

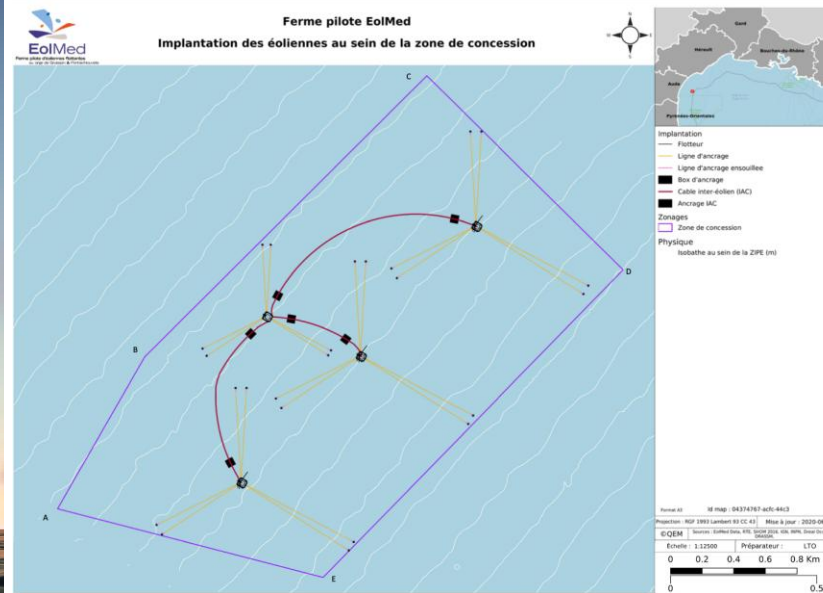


SEAGREEN 1,1 GW Bottom-Fixed project

- **JV : TotalEnergies (51%) – SSE (49%)**
- **Area : 2,865km²**
- **Distance offshore : 27km-80km**
- **Water depth : 30m - 70m**
- **Development capacity : 1,075MW**
- **114 WTG**
- **Avoid 1.6 million tonnes of CO₂ / year**
- **COD : 2024**



EOLMED 30 MW floating pre-commercial project



- ◆ Qair (70%) - TotalEnergies (20%) - Public (10%)
- ◆ 18 km offshore Gruissan
- ◆ WD = 62m
- ◆ 30 MW : 3 WTG 10MW Vestas
- ◆ COD : 2024

TYPE DE FLOTTEUR	Barge semi-submersible
DIMENSIONS	Environ 43 m x 43 m et 16 m de hauteur
DIMENSIONS DU DAMPING POOL	Environ 24,8 m x 24,8 m
TIRANT D'EAU	Environ 12 m
MATERIAU FLOTTEUR	Béton léger armé ou acier
POIDS	Environ 10 000 t



EREBUS 100 MW floating commercial project

JV: TotalEnergies (80%) - Blue Gem Wind (20%)

The project will have a 96 megawatts capacity and will be installed in an area with water depth of 70 meters. This makes Total one of the first movers in this technology in the UK, the world's largest offshore wind market.

7-10 platforms depending on turbine size



The project will cover 0.14% of the Welsh Marine Planning Area



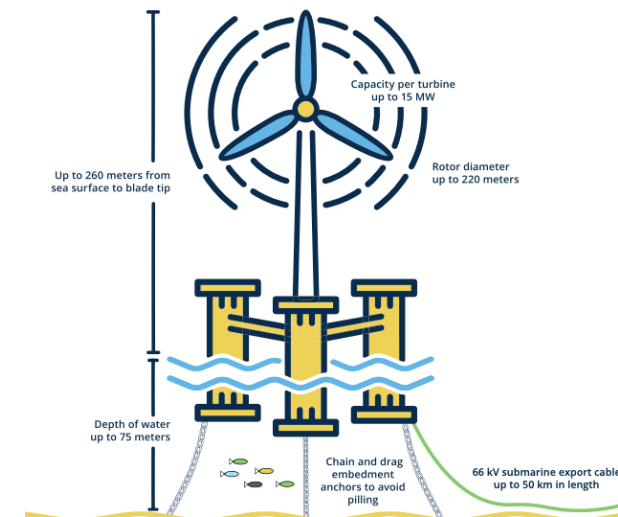
Minimum operation life of a floating wind farm = 25 years



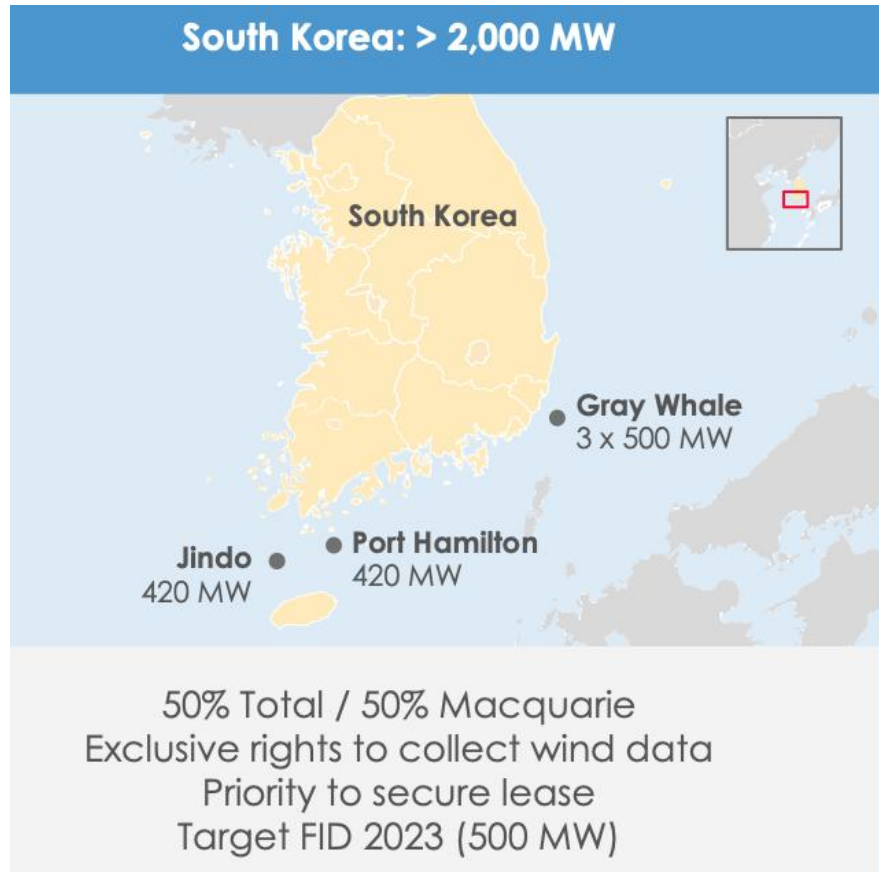
Distance from shore = 45 km
significantly reducing visual and potential conflict with other marine users
Planned installation 2026-2027



Key Metrics	Erebus
Tonnes of steel	tonnes 24,089
Metres of array cables	metres 35,900
Mooring chain mass	tonnes 10,210
Anchor Mass	tonnes 540
Crane capacity required	tonnes 700
Port-side assembly time	days 15



BADA GRAY WHALE 2 GW floating project (large scale commercial)



Project Gray Whale is a greenfield 1.5GW floating OSW farm development across 3 blocks off the east of Ulsan coastline

Project Gray Whale



Strategic locations

Robust wind condition

1

Sufficient distance from Navy firing range

2

150m-deep flat seabed allowing for any types of buoy

3

Former waste dump into green energy park

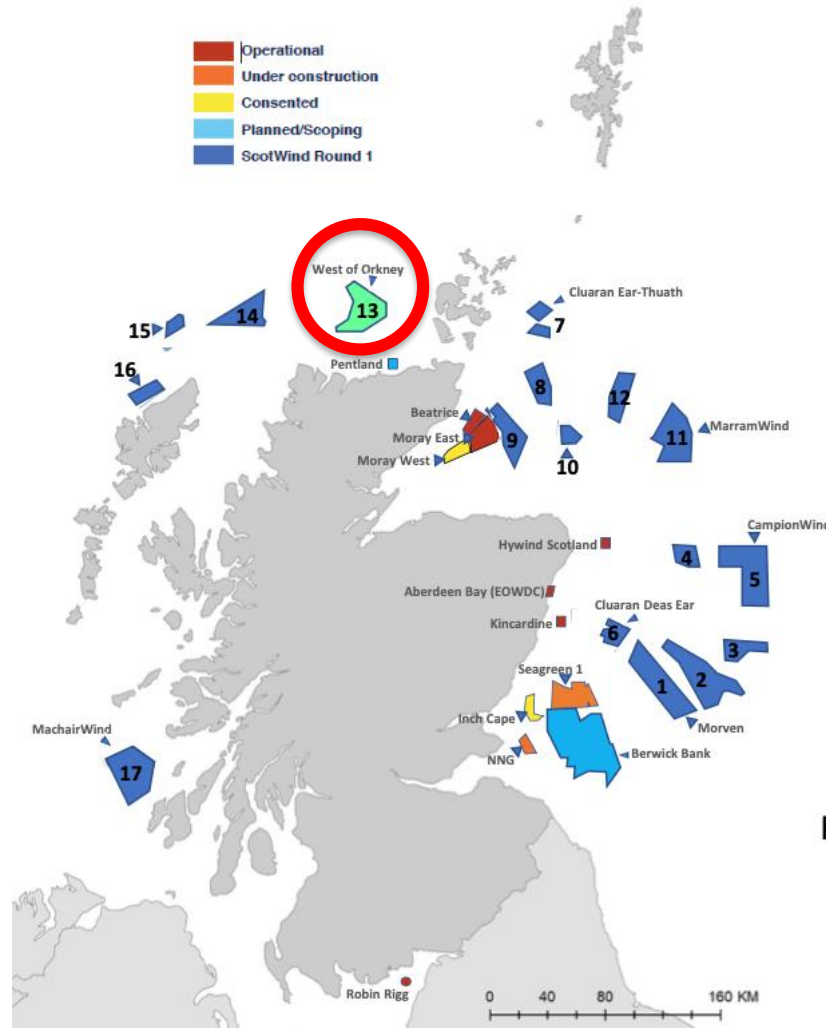
4



2021-2022 OWF awards



West Oakney Offshore Wind Farm 2 GW project (awd. 01/2021)



Offshore Wind Power



Site 13

Developer – GIG, RIDG and TotalEnergies

Name – West of Orkney

Capacity – 2,000MW

Area – 657km²

Depth – <60m

Type - Fixed

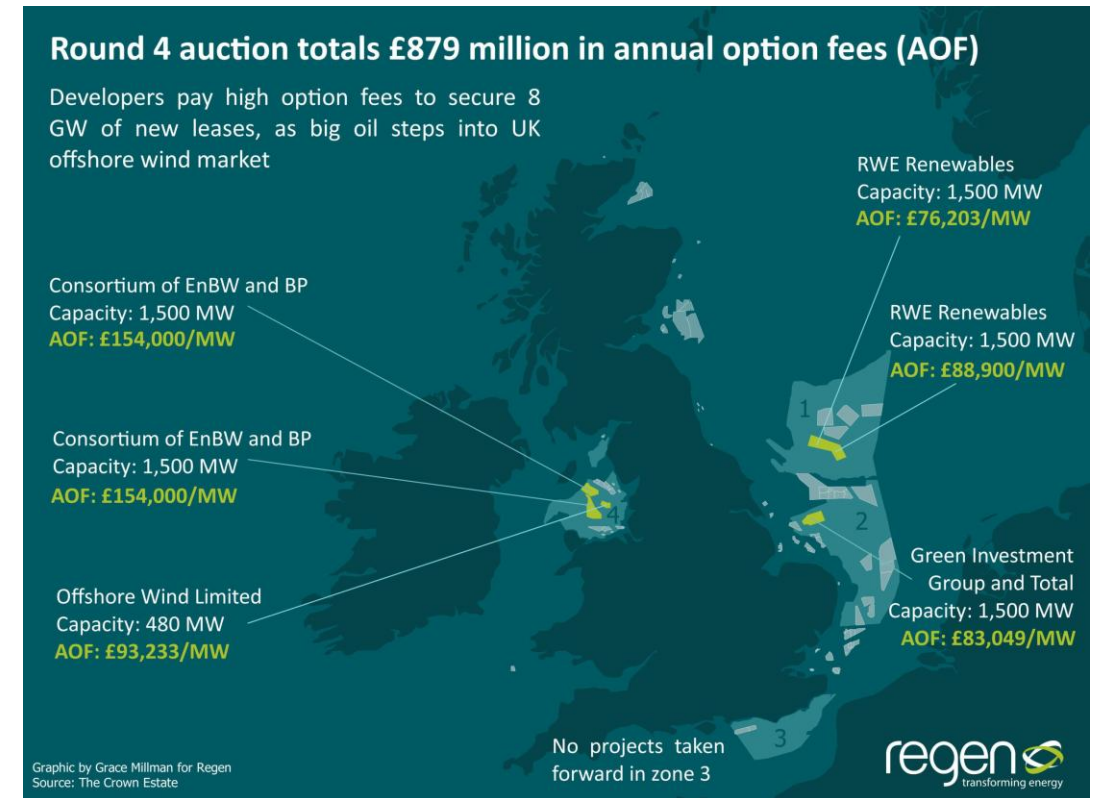
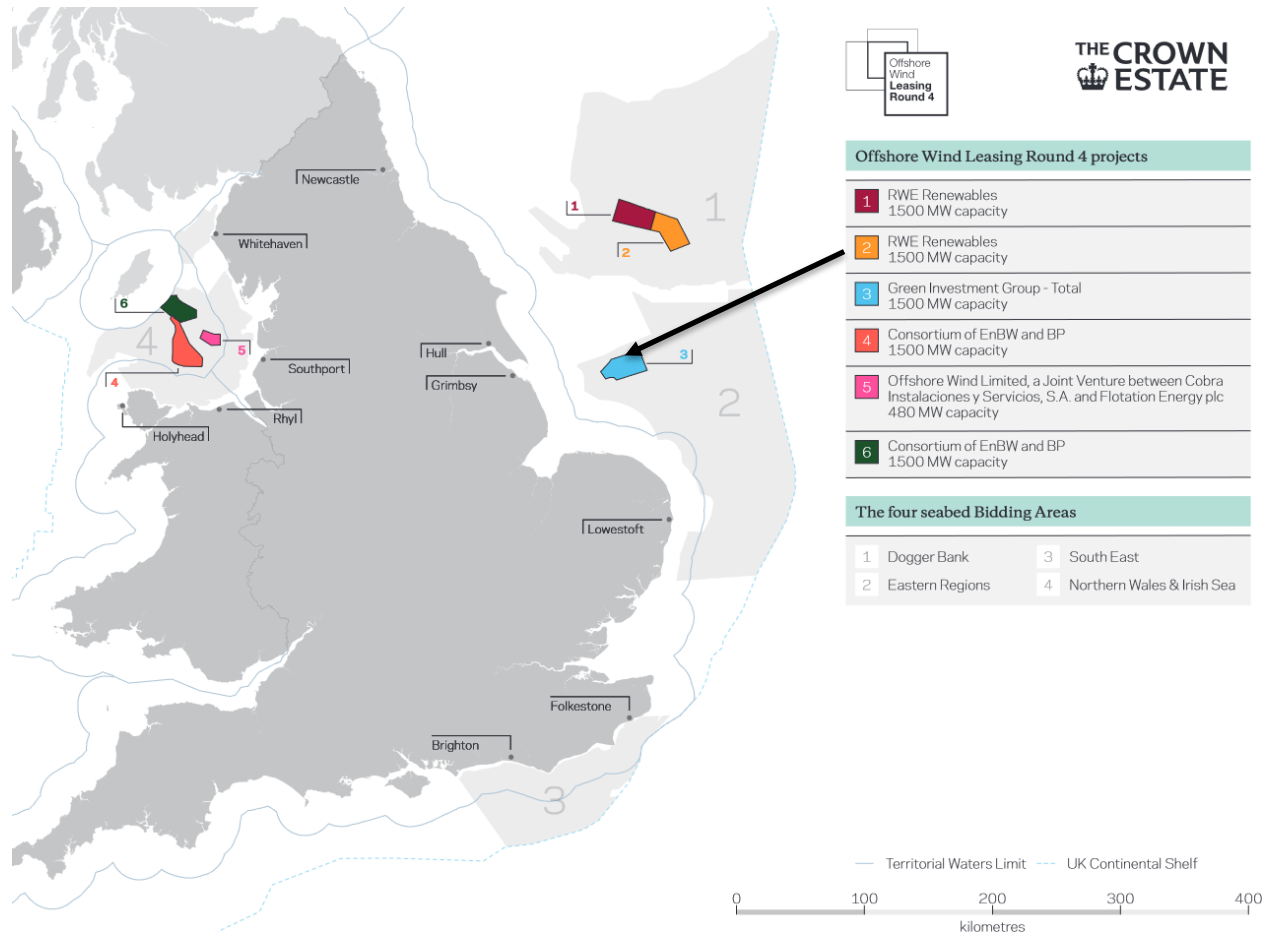
Substructure – Mono/Jackets?

Turbine Size – 20MW (100)

Flotta Hydrogen Hub - Hybrid grid/hydrogen project



Outer Downsing Offshore Wind Farm 1,5 GW project (awd. 02/2021)



Yunlin Offshore Wind Farm 640 MW project Taiwan (awd. 04/2021)

Paris, April 29th, 2021 – Total has signed an agreement with wpd to acquire a 23% interest in Yunlin Holding GmbH, the owner of Yunlin offshore wind farm located off the coast of Taiwan, around 200 kilometers southwest of Taipei. The project, currently under construction, represents production capacity of 640 megawatts (MW) and benefits from a 20-year guaranteed-price power purchase agreement (PPA) with the state-owned company Taipower of USD 250/MWh for the first 10 years and USD 125/MWh for the following 10 years . Partnership with Skybor, EGCO & Sojitz consortium.
WD = 35m, Distance to shore = 8km, 80 WTG

Source : TotalEnergies website





YUNLIN



Taiwan

Non-Operated

640 MW (80 x 8)
windmills

Bottom fixed
offshore Taiwan

WD: 8 to 35m
distance to
shore:
8 to 17 kms



CAPEX
6G€

TTE share
29%



COD

Dec, 2024

Execution

Off. Inst. 2024
campaign started
beginning of March
- ongoing

MonoPiles

Today 57 installed,
23 remaining

Wind Turbines

Today 38 installed,
42 remaining

33 Turbines export
Electricity



The YUNLIN Project – Taiwan – April 2025

- The Yunlin offshore wind farm is now fully operational
- It will power 600,000 homes in Taiwan and save 1.2 million tons of CO₂ annually
- TotalEnergies will serve as the wind farm's technical operator

Paris/Taipei, March 4th, 2025 – During a ceremony held in Taipei, TotalEnergies and its partners announced the successful inauguration of the Yunlin offshore wind farm in Taiwan, which is now fully operational and generating renewable electricity at its planned capacity of 640 MW.

A new milestone for TotalEnergies in Asia

TotalEnergies holds a 29.46% stake in Yunneng Wind Power Co., Ltd., the joint venture responsible for the project. The other stakeholders include Skyborn Renewables with 31.98%, EGCO Group with 26.56%, and Sojitz with 12%.

The development and construction of the Yunlin project were led by Skyborn with the support of the other partners. Following the Commercial Operations Date (COD), expected in June 2025, TotalEnergies will take the lead in technical operations management, whilst Skyborn Renewables will continue to lead other management services.

"We are very pleased to be inaugurating the Yunlin offshore wind farm, as we take a new step forward in our offshore wind development", said **Olivier Jouny, Senior Vice President Renewables at TotalEnergies**. "This 640 MW project will help us achieve our 2025 targets for 35 GW of gross renewable capacity and over 50 TWh of net electricity production, amounting to 10% of TotalEnergies' energy output. Our role as technical operator on Yunlin will allow us to strengthen our offshore wind competencies as we look ahead to our future projects in Germany, Denmark, and the United Kingdom", he added.

In Asia, TotalEnergies owns a renewable energy portfolio (solar, wind, batteries) of over 23 GW gross, across all stages, from development to construction and operation. Of this capacity, 50% is already operational or under construction.



The YUNLIN Project – Taiwan – April 2025

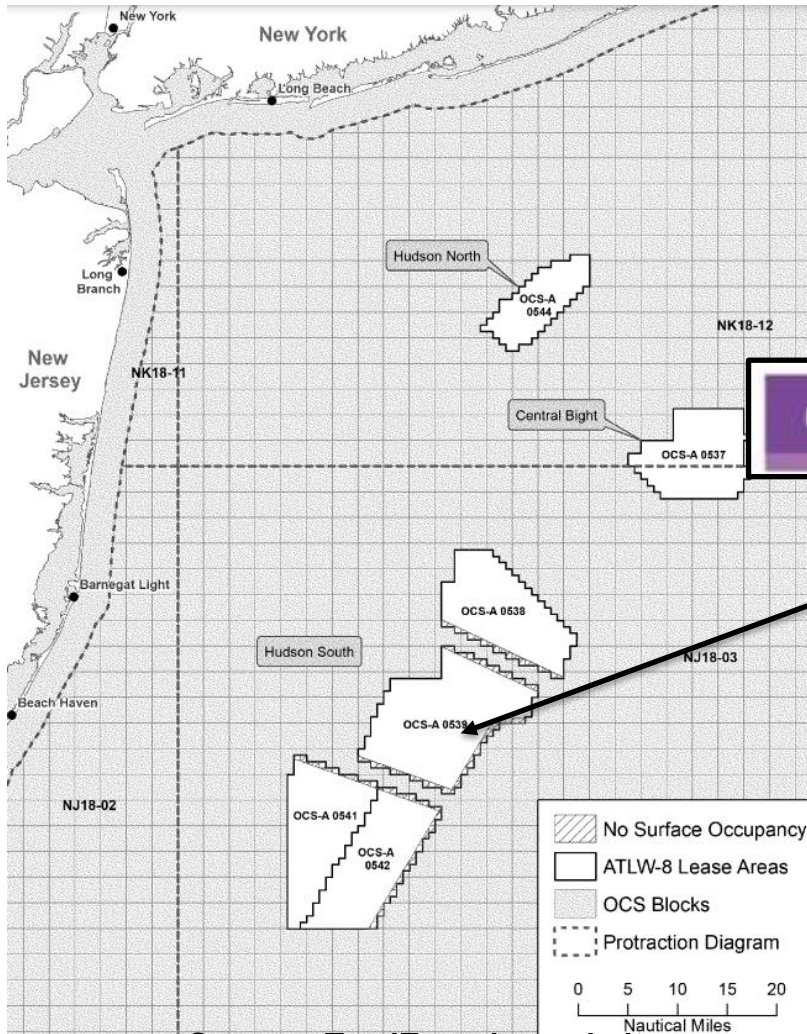
One of the largest offshore wind farms in Taiwan

The Yunlin offshore wind farm is located about 15 kilometers off the west coast of Taiwan, at water depths of up to 35 meters. The project consists of 80 wind turbines, each with 8 MW capacity. The electricity generated is fed into the Taiwanese grid and contracted to Taiwan Power Company (TPC) through two 20-year Power Purchase Agreements (PPAs) at an average rate of \$165/MWh.

The Yunlin offshore wind farm produces 2.4 TWh of renewable electricity per year, powering over 600,000 Taiwanese households and reducing CO₂ emissions by approximately 1.2 million tons.



New York Bight Offshore Wind Farm 3 GW project USA (awd. 02/2022)



Source : TotalEnergies website

New York Bight tender (100%)
February 2022

3 GW

- 50-year lease for 795 M\$_{100%}
- FID expected by 2026 with COD by 2028
- PPA tenders in 2023

OCS-A 0539 Bight Wind Holdings, LLC, \$1,100,000,000



Carolina Long BayOffshore Wind Farm 1 GW project USA (awd. 05/2022)

North Carolina tender (100%)
May 2022

> 1 GW

- 30-year lease for 160 M\$_{100%}
- FID expected by 2027 with COD by 2030

Provisional Winner	Lease Area	Acres	Winning Bid
TotalEnergies Renewables USA, LLC	OCS-A 0545	54,937	\$160,000,000



Source : TotalEnergies website



2-5

Wind Economics Fundamentals



**LCOE is very dependant upon changes of the environment (prices of fuels, cost of new nuclear and production costs of solar energy in particular)
For wind energy and solar energy, cost of intermittency has to be added
LCOE is also very dependant upon the Discount rate.
(See Book 2 – Energy, Chapter 17)**



Levelized Cost of Electricity production (LCOE) = Discounted Costs/Discounted Production

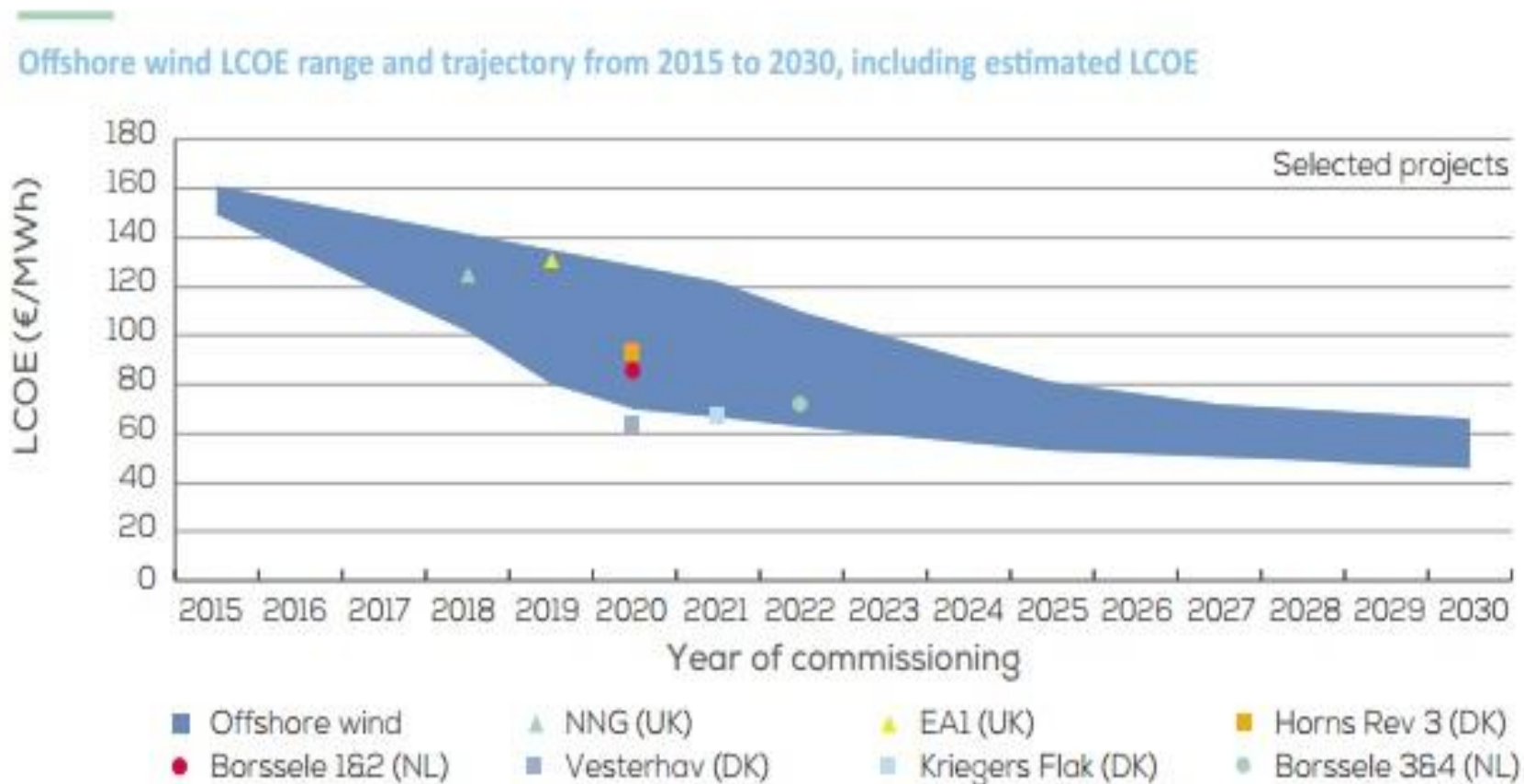
$$LCOE = \sum_{k=0}^{k=n} \frac{C_k + O_k + F_k}{(1+i)^k} / \sum_{k=0}^{k=n} \frac{Q_k}{(1+i)^k}$$

- *Q : Production of Electricity*
- *C : Capital Expenditures*
- *O : Operating Expenses*
- *F : Fuel Expenses*
- *n : Economic Plant Life*
- *i : Discount Rate*
- *Due to discounting, decommissioning costs have a negligible effect (included in Capex)*
- *For Renewables, Intermittency Costs are not included*

Nota: In the following, raw data from IEA, US DOE, UK DBEIS, IRENA, Lazard, Fraunhofer ISE, WNA,.....



LCOE for Wind Offshore very much depend upon the anticipated year of commissioning



Source: BVG Associates for WindEurope

Source: WindEurope



Wind Offshore

Some considerations on LCOE



Wind Offshore/OECD Region/Average figures – LCOE Comparison 2019 & Perspectives 2030

Wind Offshore – Standard Project Year 2019

Nominal Capacity	MW	250
Capacity each turbine	MW	5
Nb of turbines		50
Duration life	Years	25
Load factor	%	40
Electricity Generation	MWh/year	876000
Total Electricity Generation	MWh	21900000
Capex	€/kW	4000
Total Capex	M€	1000
Constant Annuity @ 0%	M€	42
Constant Annuity @ 5%	M€	72
Constant Annuity @ 8%	M€	94
Opex	€/MWh	30
Opex per year	M€	26
Total Opex	M€	657
Fuel cost	M€	0
Decommissioning	M€	50
Total cost	M€	1707
LCOE (not discounted)	€/MWh	78
LCOE @ 5%	€/MWh	112
LCOE @ 8%	€/MWh	138
Constant Annuity @ 0%	%	4,00
Constant Annuity @ 5%	%	7,10
Constant Annuity @ 8%	%	9,37

Wind Offshore – Standard Project Year 2030

Nominal Capacity	MW	500
Capacity each turbine	MW	10
Nb of turbines		50
Duration life	Years	25
Load factor	%	45
Electricity Generation	MWh/year	1971000
Total Electricity Generation	MWh	49275000
Capex	€/kW	2500
Total Capex	M€	1250
Constant Annuity @ 0%	M€	53
Constant Annuity @ 5%	M€	90
Constant Annuity @ 8%	M€	118
Opex	€/MWh	15
Opex per year	M€	30
Total Opex	M€	739
Fuel cost	M€	0
Decommissioning	M€	63
Total cost	M€	2052
LCOE (not discounted)	€/MWh	42
LCOE @ 5%	€/MWh	61
LCOE @ 8%	€/MWh	75
Constant Annuity @ 0%	%	4,00
Constant Annuity @ 5%	%	7,10
Constant Annuity @ 8%	%	9,37



Wind Offshore/OECD Region/Average figures – LCOE Comparison 2019 & Perspectives 2030

Wind Offshore – Standard Project Year 2019

Nominal Capacity	MW	250
Capacity each turbine	MW	5
Nb of turbines		50
Duration life	Years	25
Load factor	%	40
Electricity Generation	MWh/year	876000
Total Electricity Generation	MWh	21900000
Capex	€/kW	4000
Total Capex	M€	1000
Constant Annuity @ 0%	M€	42
Constant Annuity @ 5%	M€	72
Constant Annuity @ 8%	M€	94
Opex	€/MWh	30
Opex per year	M€	26
Total Opex	M€	657
Fuel cost	M€	0
Decommissioning	M€	50
Total cost	M€	1707
LCOE (not discounted)	€/MWh	78
LCOE @ 5%	€/MWh	112
LCOE @ 8%	€/MWh	138
Constant Annuity @ 0%	%	4,00
Constant Annuity @ 5%	%	7,10
Constant Annuity @ 8%	%	9,37

Floating Wind Offshore Year 2030

Nominal Capacity	MW	500
Capacity each turbine	MW	10
Nb of turbines		50
Duration life	Years	25
Load factor	%	45
Electricity Generation	MWh/year	1971000
Total Electricity Generation	MWh	49275000
Capex	€/kW	4000
Total Capex	M€	2000
Constant Annuity @ 0%	M€	84
Constant Annuity @ 5%	M€	144
Constant Annuity @ 8%	M€	189
Opex	€/MWh	22
Opex per year	M€	43
Total Opex	M€	1084
Fuel cost	M€	0
Decommissioning	M€	100
Total cost	M€	3184
LCOE (not discounted)	€/MWh	65
LCOE @ 5%	€/MWh	95
LCOE @ 8%	€/MWh	118
Constant Annuity @ 0%	%	4,00
Constant Annuity @ 5%	%	7,10
Constant Annuity @ 8%	%	9,37





Solar Energy



BOOK 7 - TABLE OF CONTENTS

1. Global Remarks on Renewable Energy Sources

- Renewables in the Energy Mix –Trends/Perspectives – Investments – Potential/Diffusion/Network – Subsidies – Intermittency – Competitiveness – France PPE – Total Positioning – Criticality of Mineral Matters Resources – Dismantelment/End Life Equipment Recycling

2. Wind Energy

3. Solar Energy

4. Biomass Energy

5. Geothermal Energy

6. Marine Energy



Non, Nasr Eddin le Hodja n'a pas tout à fait raison!



On aimait bien embarrasser Nasr Eddin avec des questions oiseuses ou carrément impossibles à résoudre. Un jour, on lui demande:

- **Nasr Eddin, toi qui es versé dans les sciences et les mystères, dis-nous quel est le plus utile, du soleil ou de la lune.**
- **La lune, sans aucun doute. Elle éclaire quand il fait nuit, alors que ce stupide soleil luit quand il fait jour.**



No, Nasr Eddin Hodja is not right !



People liked to embarrass Nasr Eddin with silly questions or problems impossible to solve. One day he is asked:

- Nasr Eddin, you are knowledgeable in all sciences, tell us which is more useful to us, the sun or the moon.
- The moon, without doubt. It give light at night when this stupid sun shines in daylight!



Table of contents

- 1. Solar basics**
- 2. Solar technology**
- 3. Solar economics**



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Solar basics

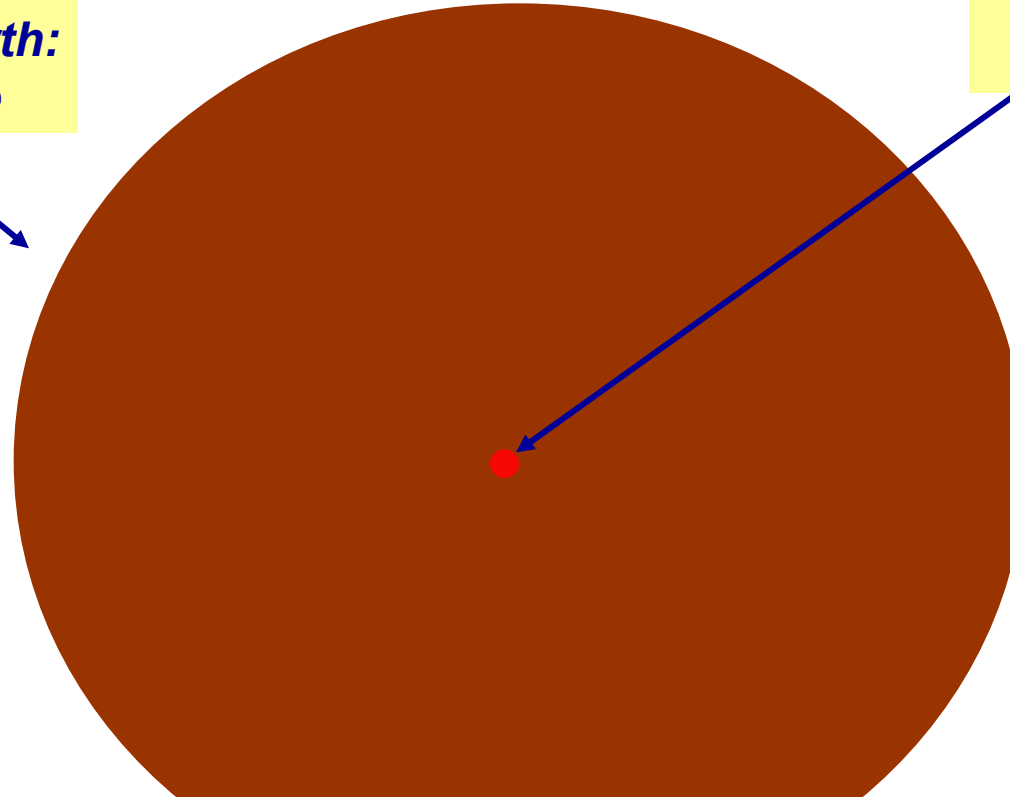


Solar power is a natural long term energy champion

**Total solar power
received on earth:
130 000 Gtoe**

**Assuming a
conversion
factor of 17%
in average:
22 000 Gtoe**

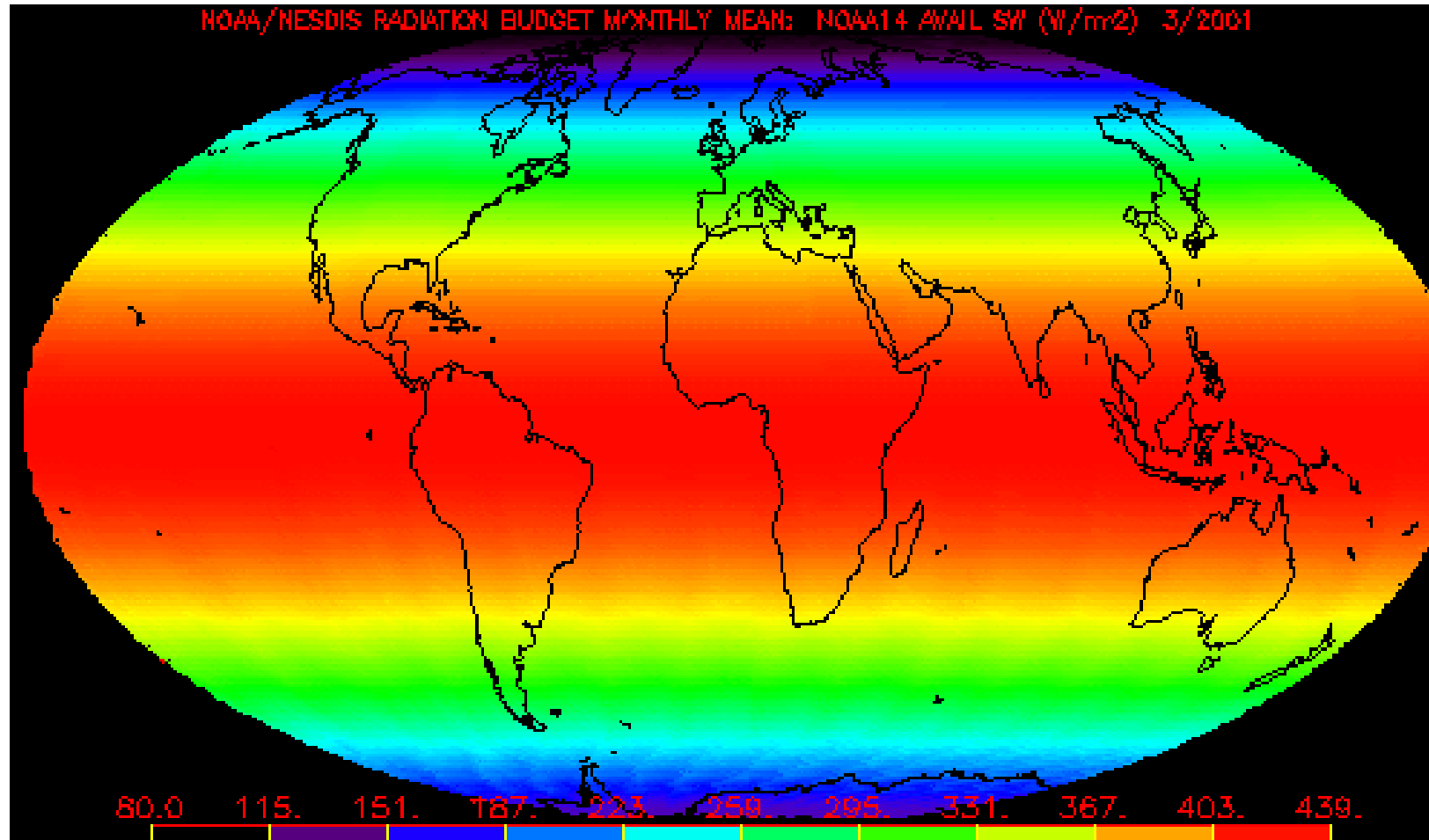
**World need
10-20 Gtoe**



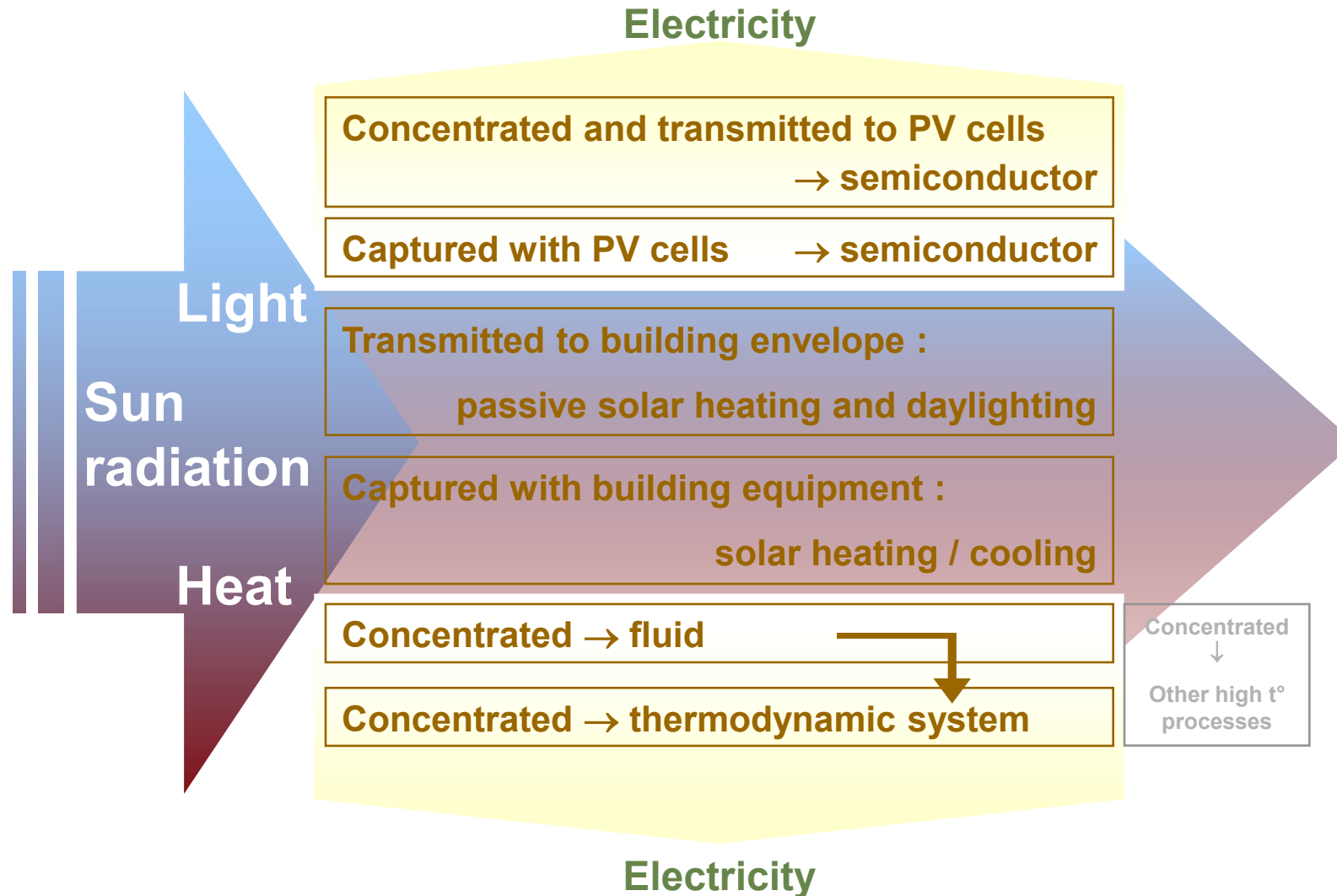
**Total solar power received on earth in average = 343 W/m²
= 176 000 TW
Total solar energy received # 1 540 000 000 TWh # 130 000 Gtoe**



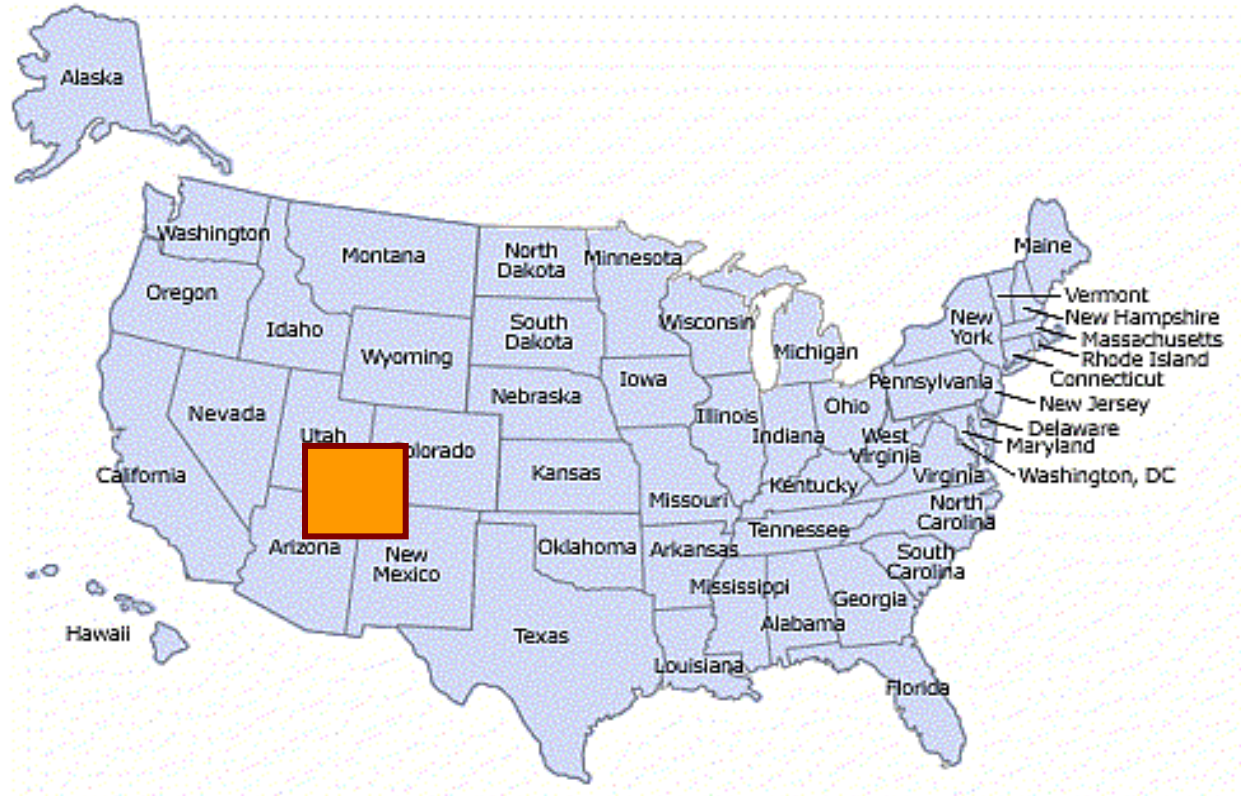
Average solar radiation = 342 W/m²



Radiative power at the user side



An Example: Solar potential and US global energy demand: 2,5 Gtoe



Potentially satisfied by covering 2% of the surface with solar modules 10% efficiency

2% = surface occupied by roads (same as what would solar require !)

40% of the surface is dedicated to food production

Solar pannels are 10 to 20 times more efficient than plants to « capture » solar energy



Solar markets

**Off-grid
residential**



**Off-grid
professional**



**On-grid
distributed**



**On-grid central
Solar Plants**



**Consumer
modules**



3-2

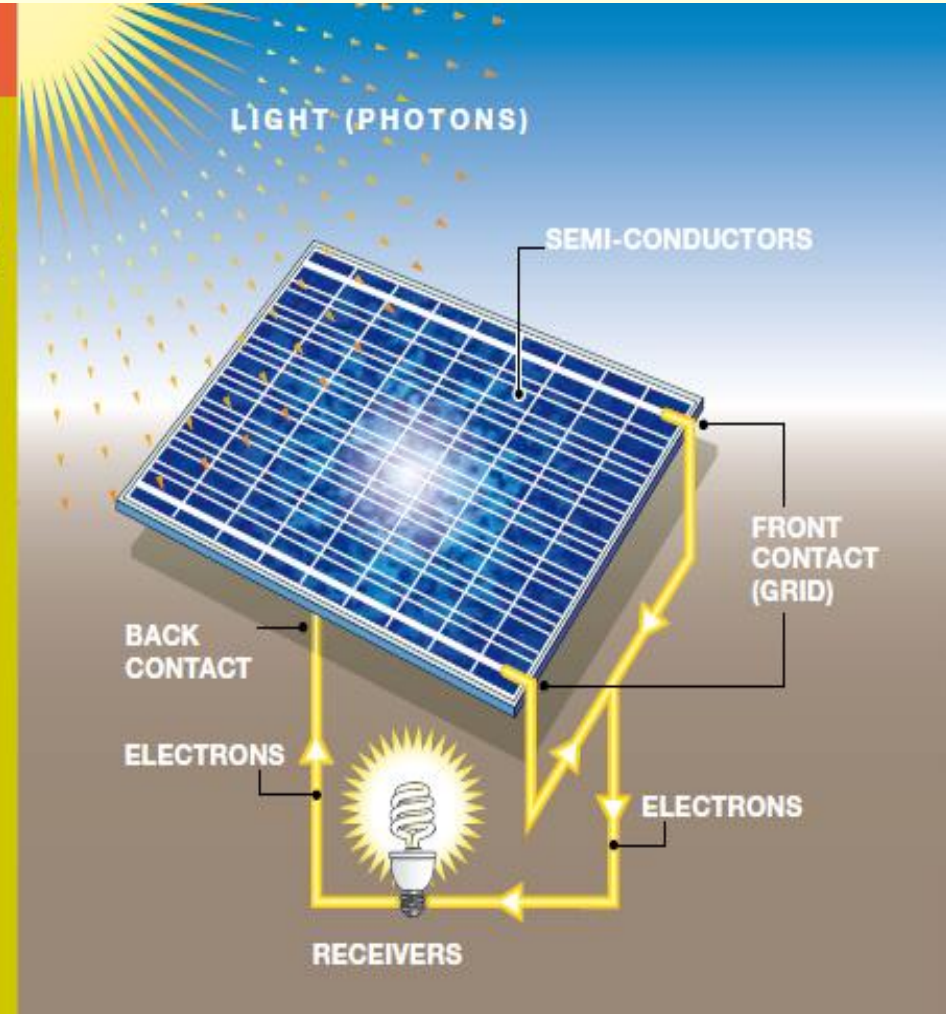
Solar technology



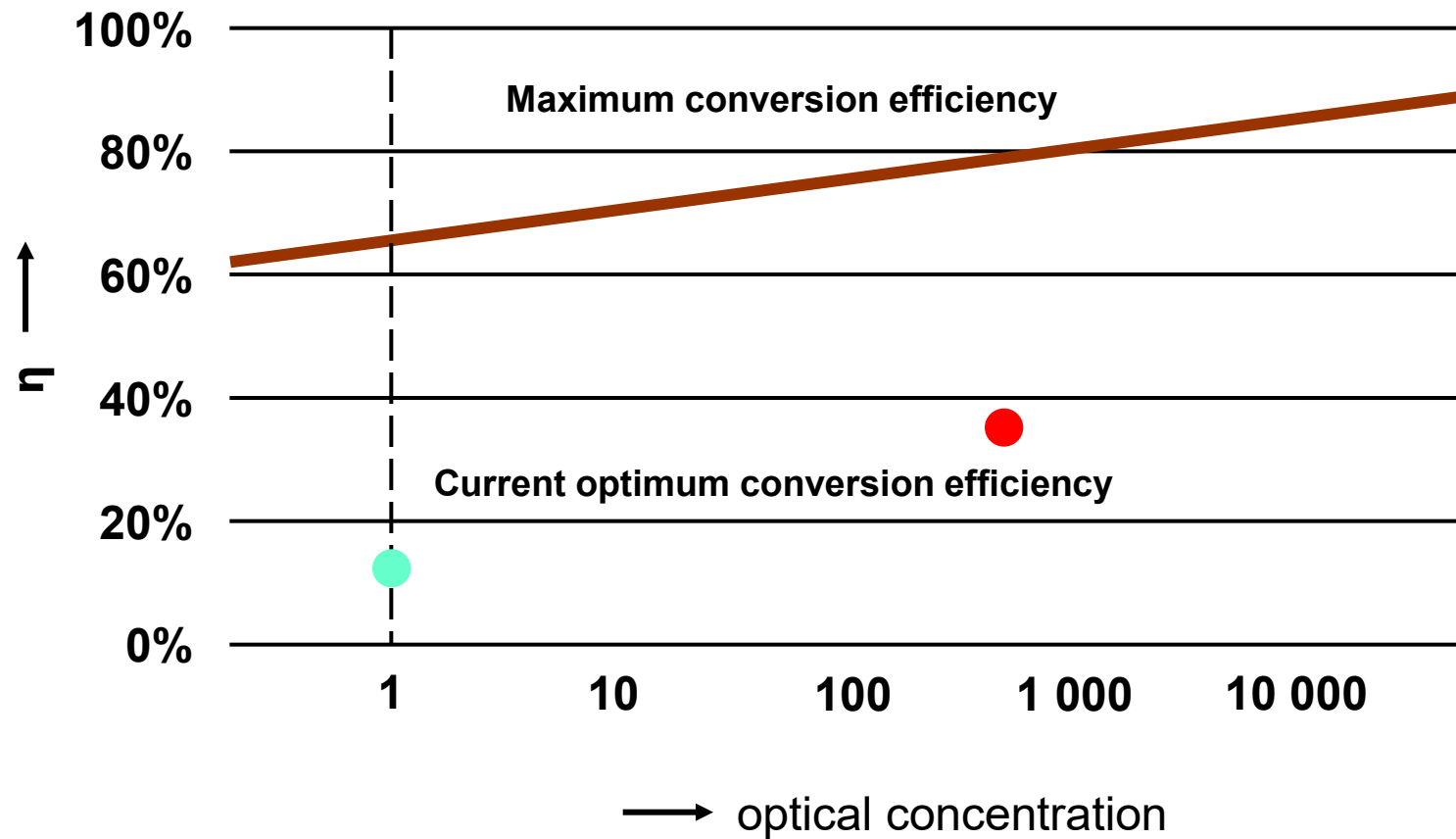
Photovoltaic Principle

A SOLAR PHOTOVOLTAIC CELL:
DIRECT CONVERSION OF LIGHT ENERGY
INTO ELECTRICAL ENERGY

From **5%** to about **40%**:
depending on the technology used and its stage
of development (laboratory research, prototype,
commercial module), the output of photovoltaic
cells can vary. Their cost can fluctuate greatly
too. The best silicon cells actually being marketed
today have a sunlight conversion rate of between
15% and 20%



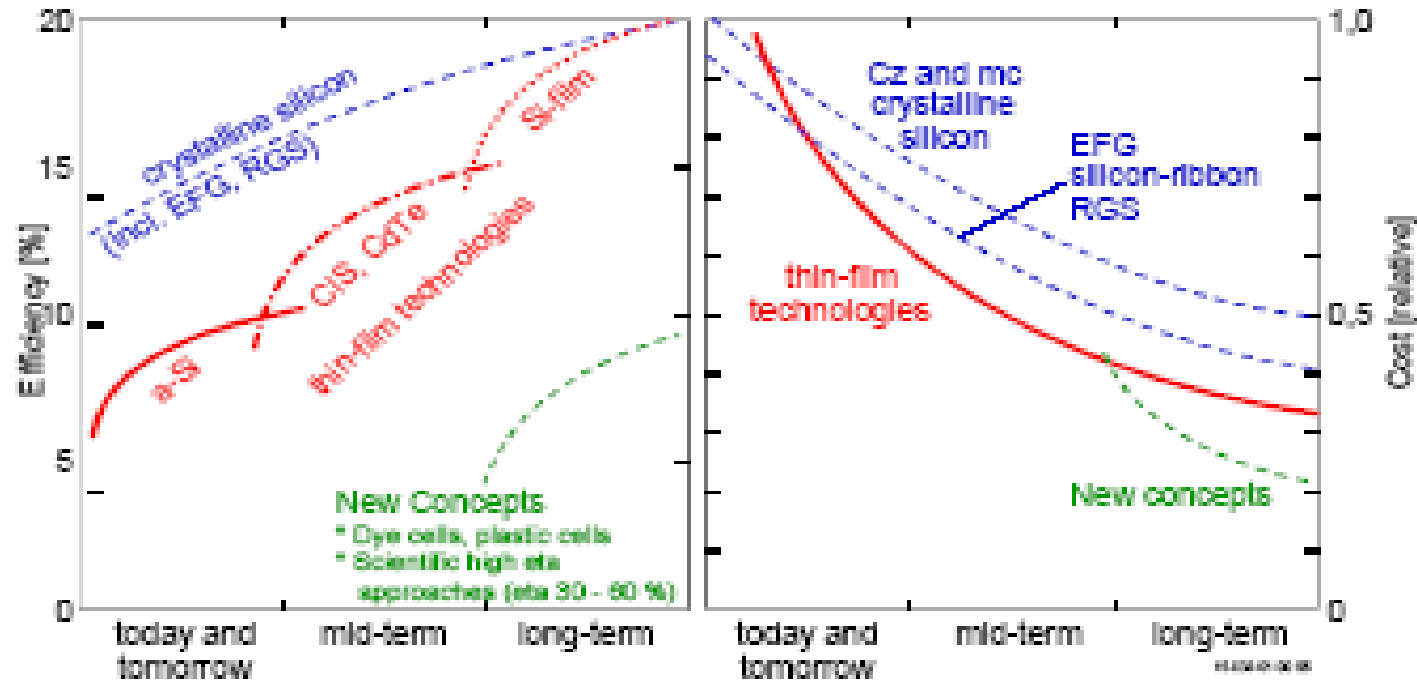
Thermodynamic limits of photovoltaic solar energy conversion efficiency



Source: Fraunhofer Institute



PV Technologies: Three main families



Source: EPIA / RWE Schott Solar

Crystalline Silicon: mono (FZ, CZ), multi, ribbon

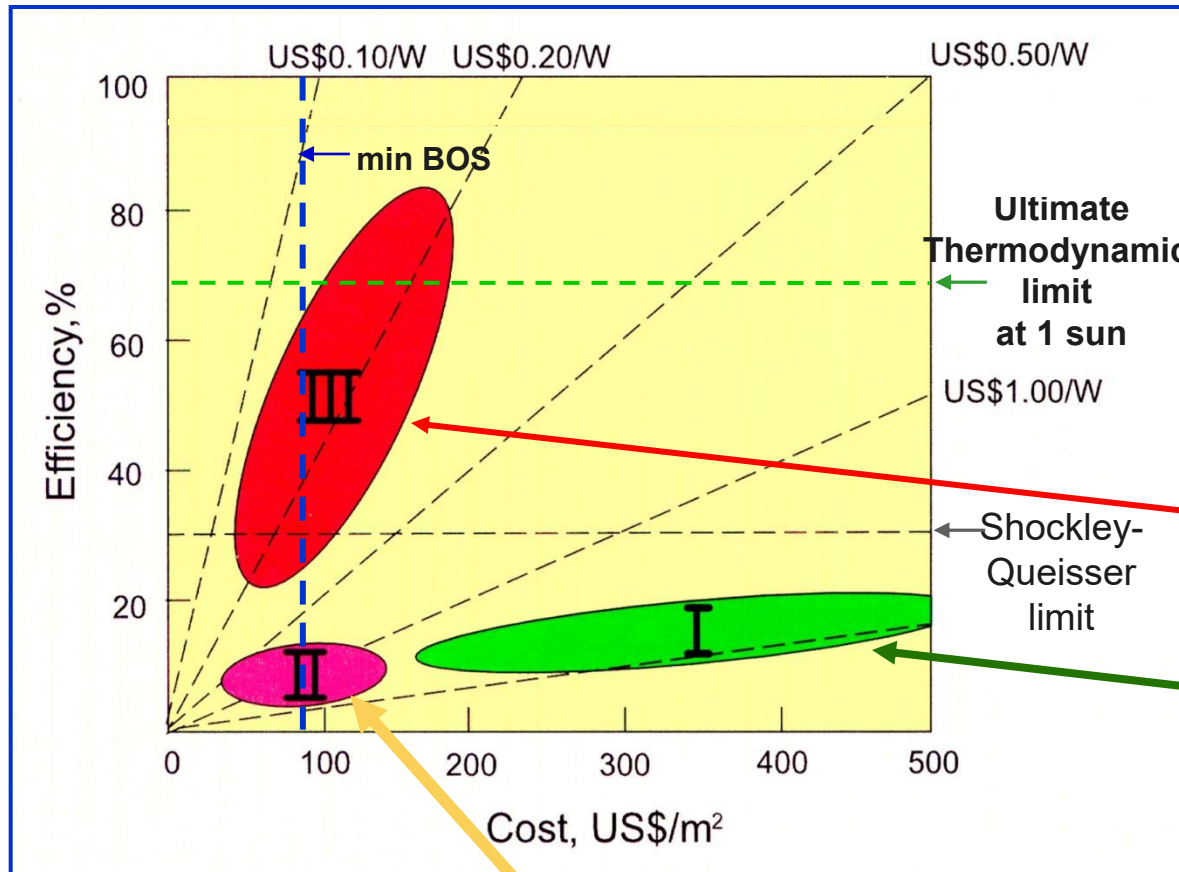
Thin Films: One « process technology », irrespective of the active material (Si, CdTe, CIS)

Organic and polymer cells

Not represented: advanced multispectral cells (could be considered as « thin film »)



The three generations of Solar PV



Multijunctions
Quantum dots
etc...

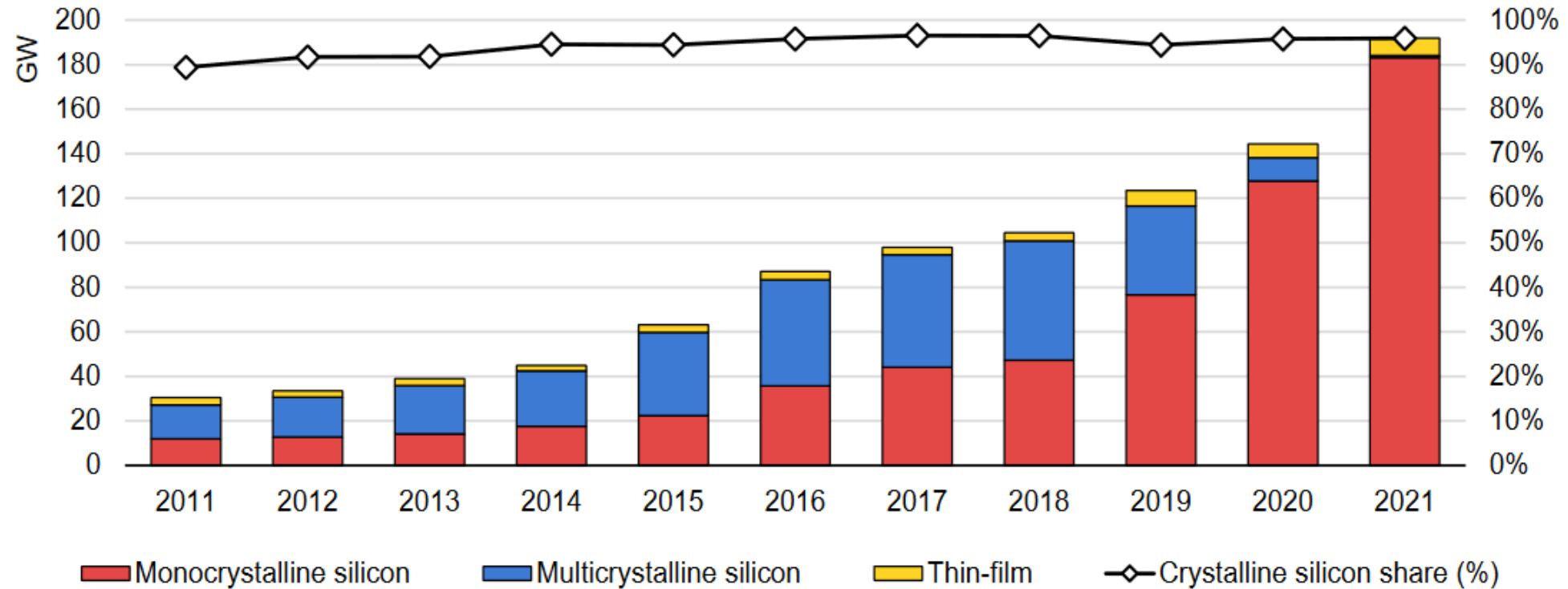
Crystalline silicon

Monogap (in)organic thin films



PV Technologies: Three main families & Production Evolution

Solar PV module production by technology, 2011-2021



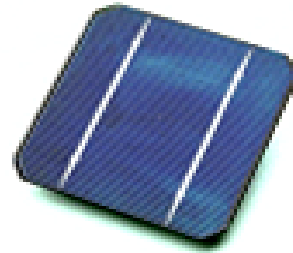
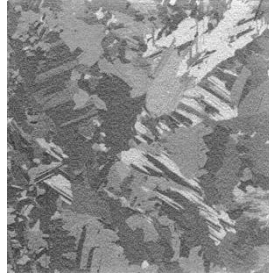
IEA. All rights reserved.

Source: IEA analysis based on BNEF (2022a), IEA PVPS, SPV Market Research, RTS Corporation and PV InfoLink.

Source: IEA 2022, Special Report on Solar PV Supply Chain



The crystalline silicon solar PV value chain



Purified silicon

Wafers

Cells

Modules

Systems

**Chemical or
Metallurgical
process
for purification**

**Casting
Sawing**

**Surface
treatments**

**Assembly
Lamination**

**Installation
Operation**

In 2011, Total acquired 60% of Sunpower (Sales 2,2 G\$) which previously purchased Tenesol

Photovoltech
(founded in 2001)
(Total 47,8%)
Sales 2010: 80 M€
Closed in 2012

Tenesol
(founded in 1983)
(Total 50%, then 100%)
Sales 2010: 240 M€
Sold to Sunpower



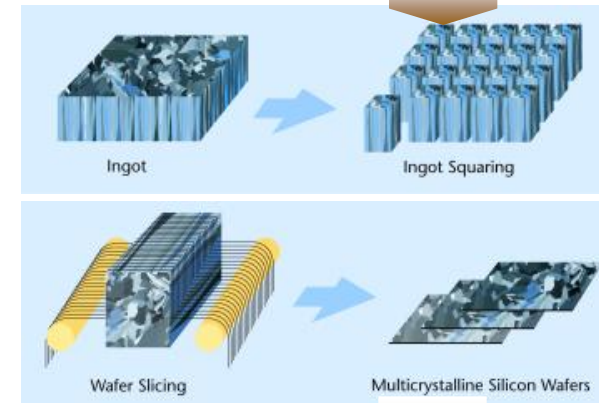
First generation: Silicon-based solar cells

◆ Silicon material: Si

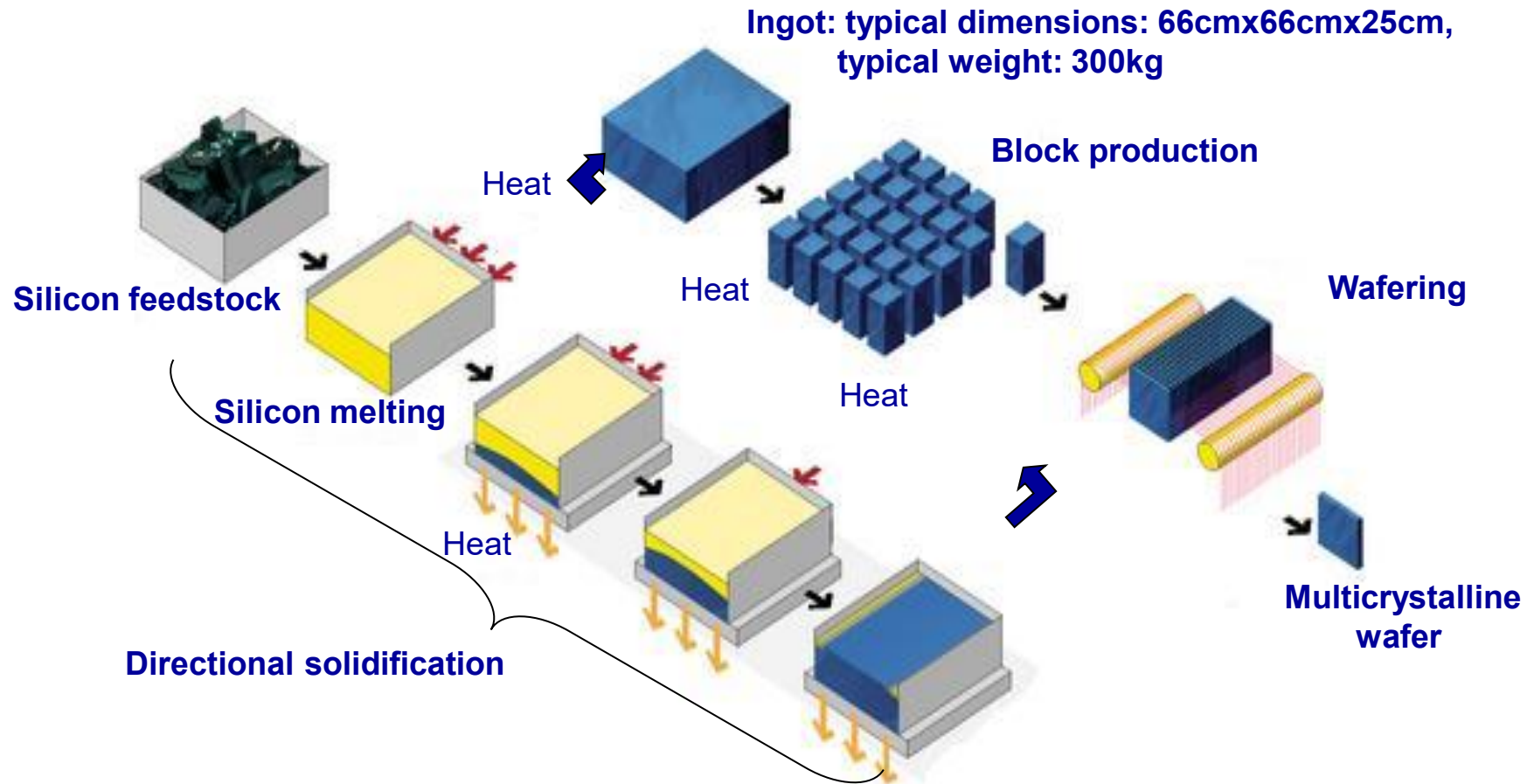
- **Non-toxic and abundant** (~25% of earth's crust)
- **Excellent** electronic, chemical and mechanical properties
- Monoelemental semiconductor with an almost ideal (1.1eV) bandgap for terrestrial applications
- Gives long-term **stable** solar cells and modules
- Currently used in microelectronics
- Si wafer solar cells >90% of PV terrestrial modules
- Multicrystalline Si cells, $\eta \sim 15\%$:
 - **Thinner cells: less material and energy**
 - **Large area devices**
 - **Higher efficiencies: 15% @ 20% and higher**



Si Crystallisation Furnace

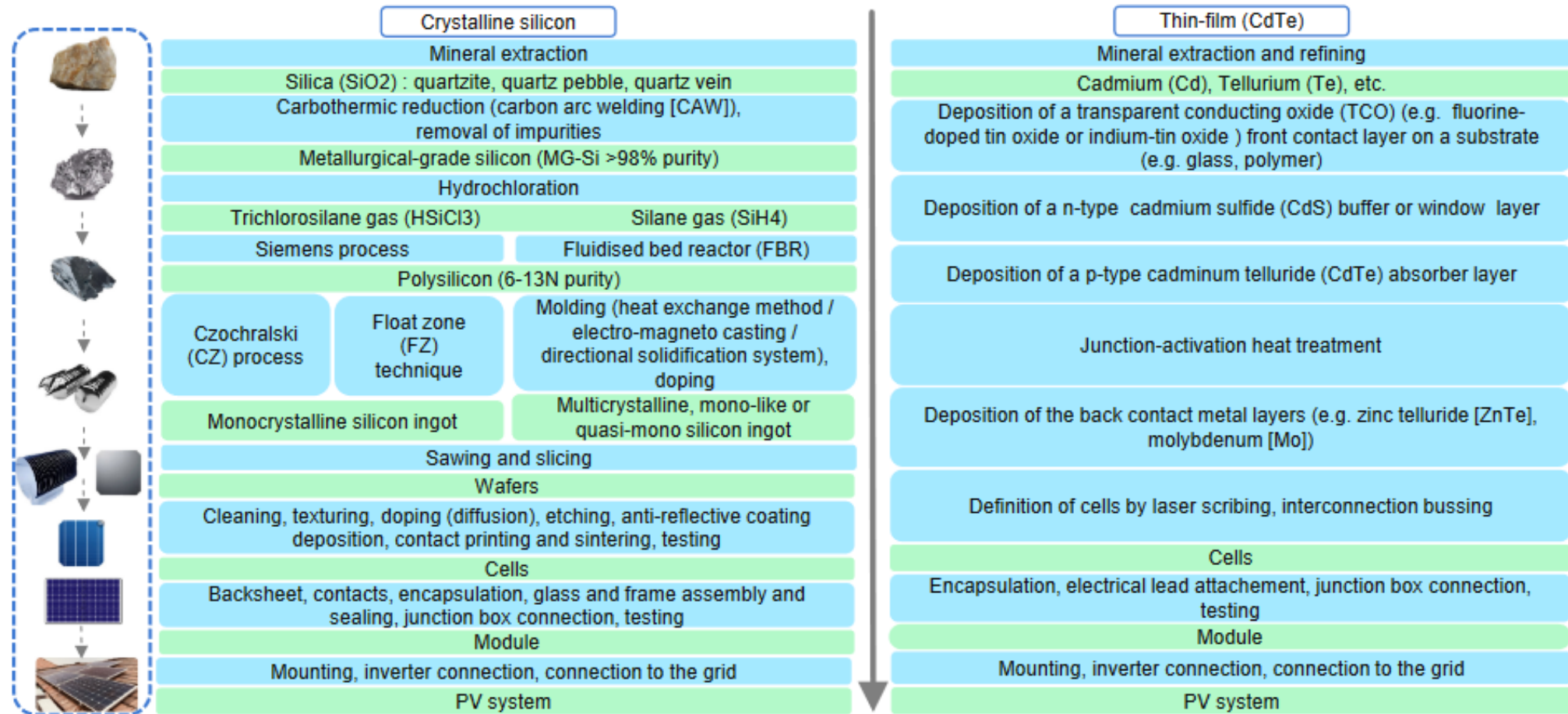


From solar grade silicon to wafer



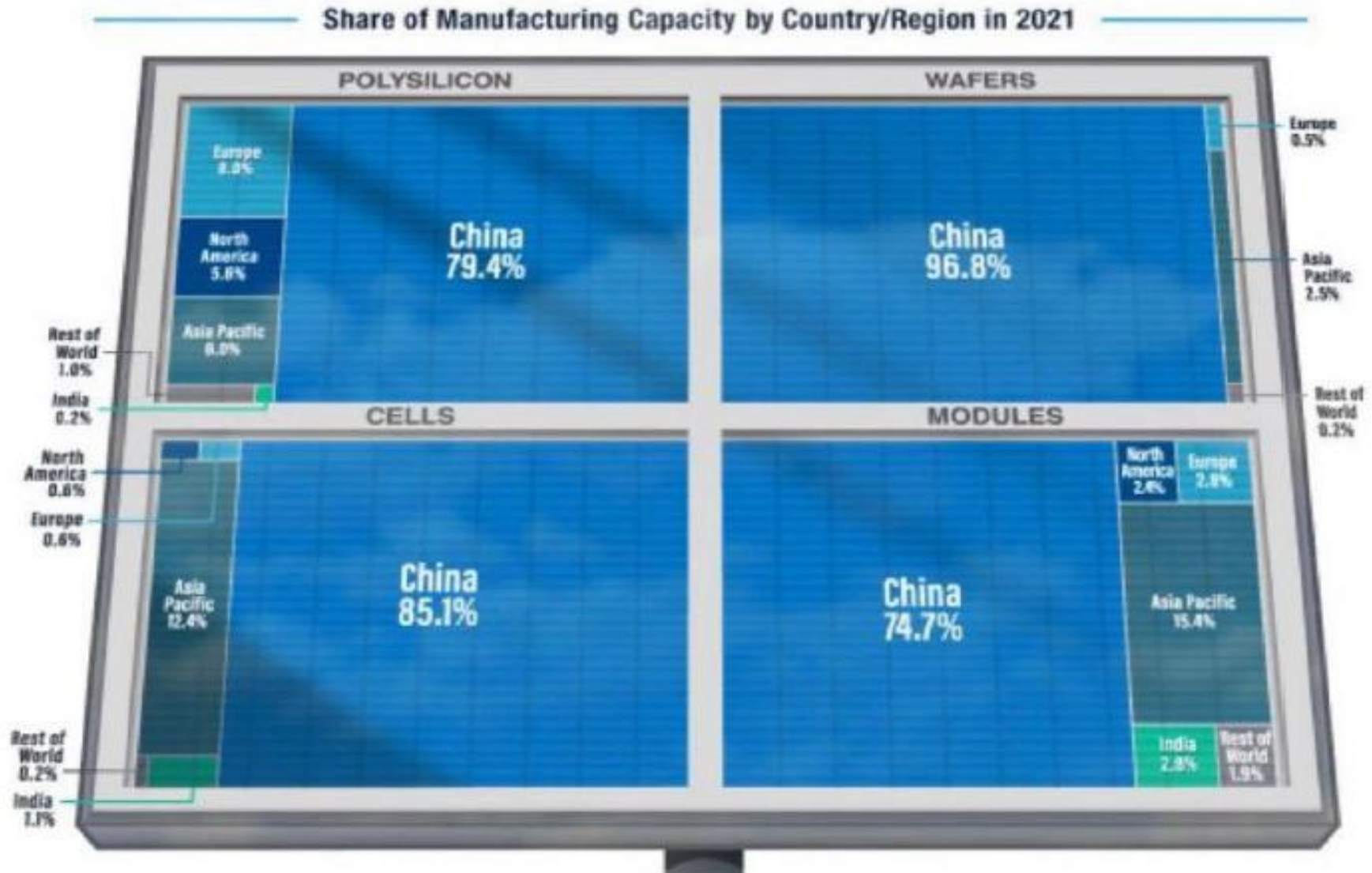
Manufacturing Steps: Crystalline silicon vs Thin-Film

Simplified manufacturing from raw materials for c-Si and CdTe solar PV systems

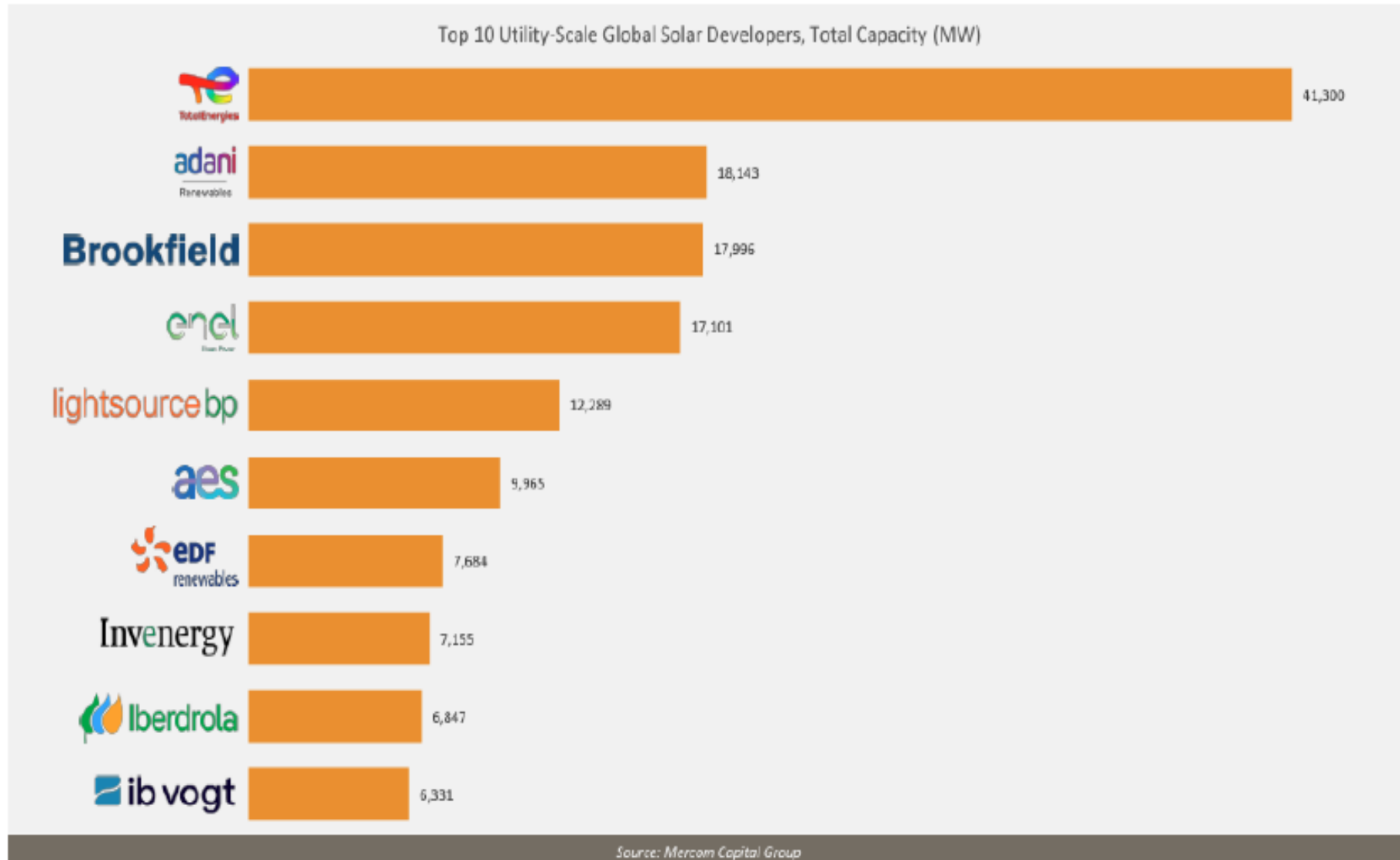


Source: IEA 2022, Special Report on Solar PV Supply Chain

Who controls the Solar panels Supply Chain?

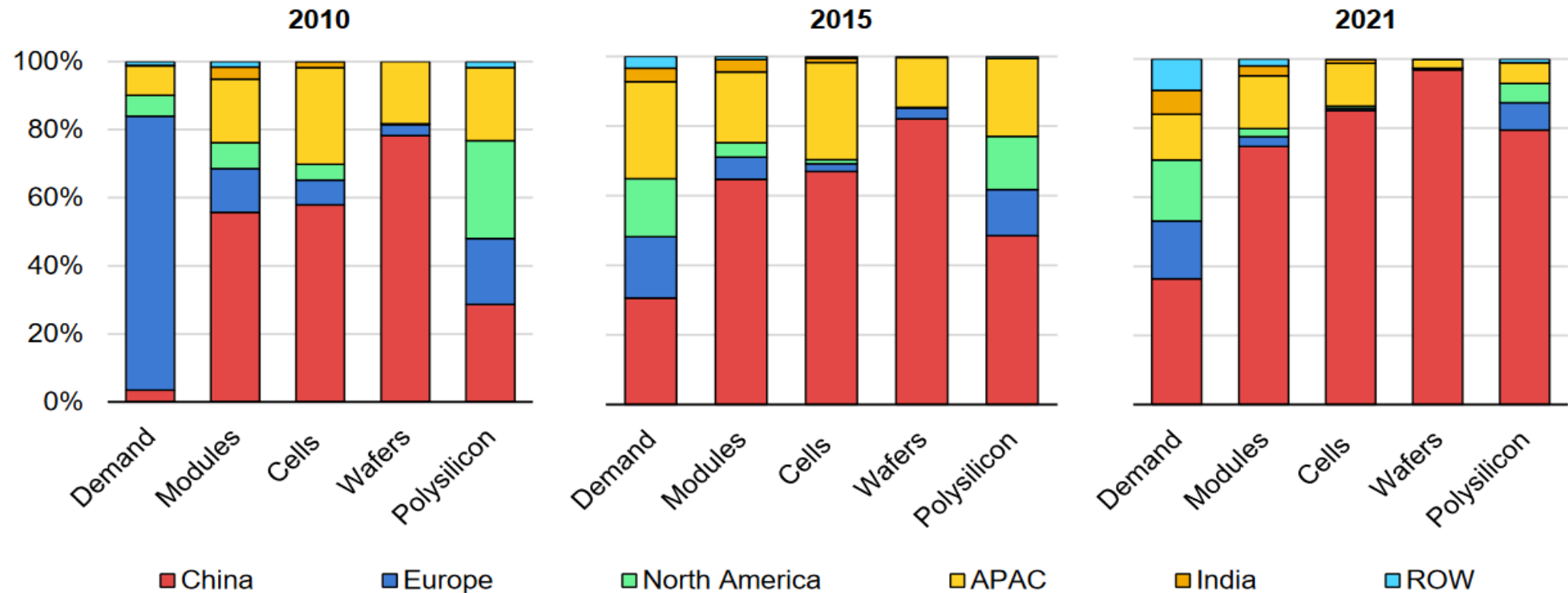


The top 10 Utility Scale Solar Developers



Solar PV Manufacturing: China the Leader

Solar PV manufacturing capacity by country and region, 2010-2021



IEA. All rights reserved.

Notes: APAC = Asia-Pacific region excluding India. ROW = rest of world.

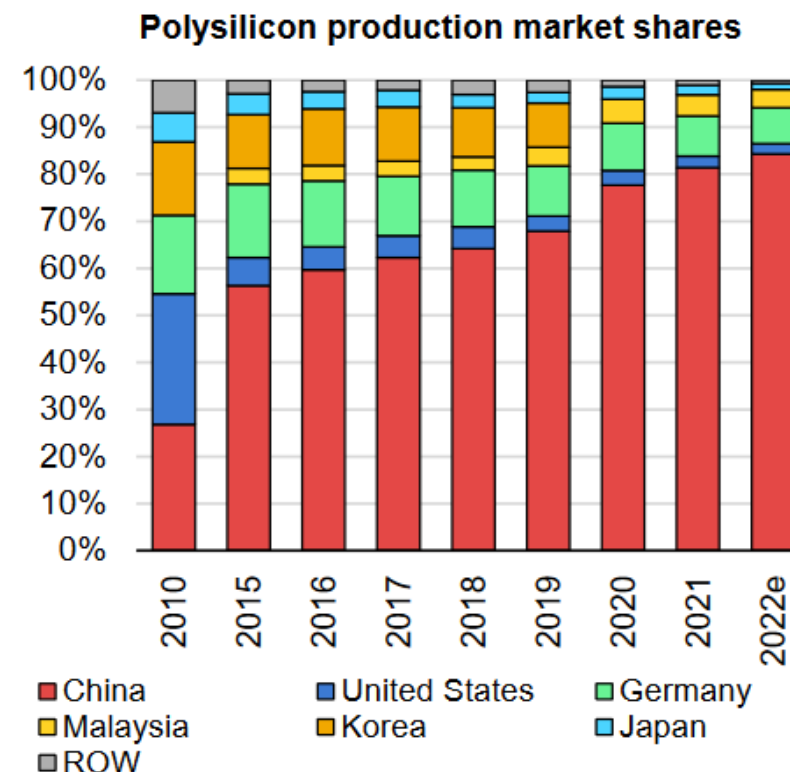
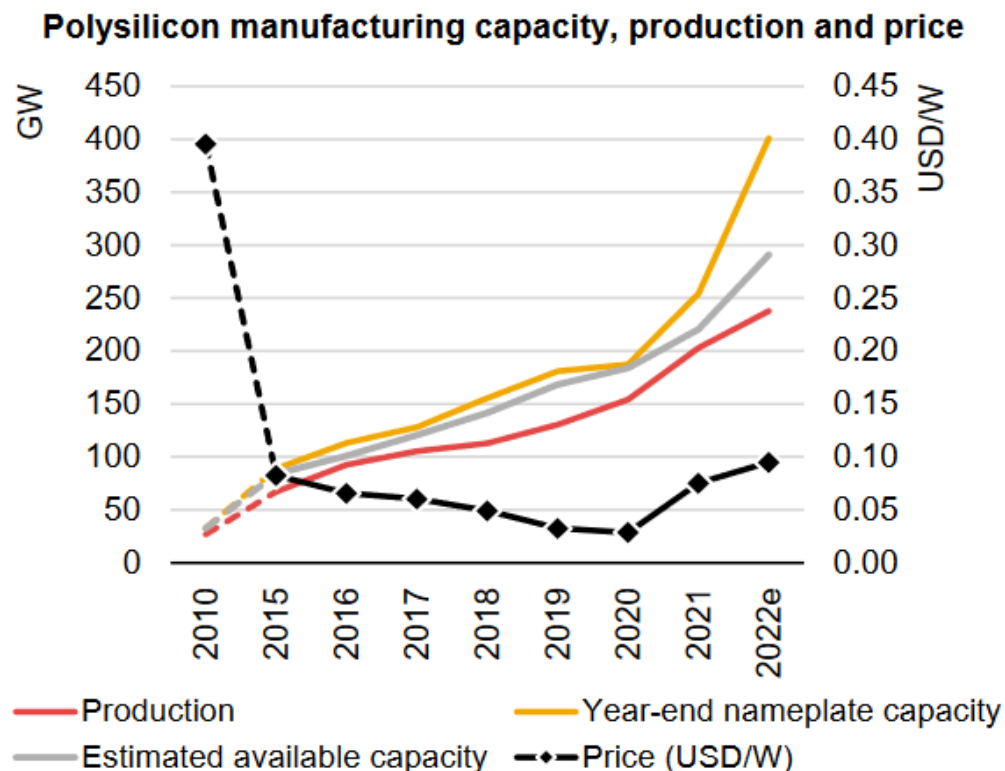
Source: IEA analysis based on BNEF (2022a), IEA PVPS, SPV Market Research, RTS Corporation and PV InfoLink.

Source: IEA 2022, Special Report on Solar PV Supply Chain



Polysilicon Manufacturing: China the Leader

Prices divided by 10 from 2010 to 2020



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Note: ROW = rest of world.

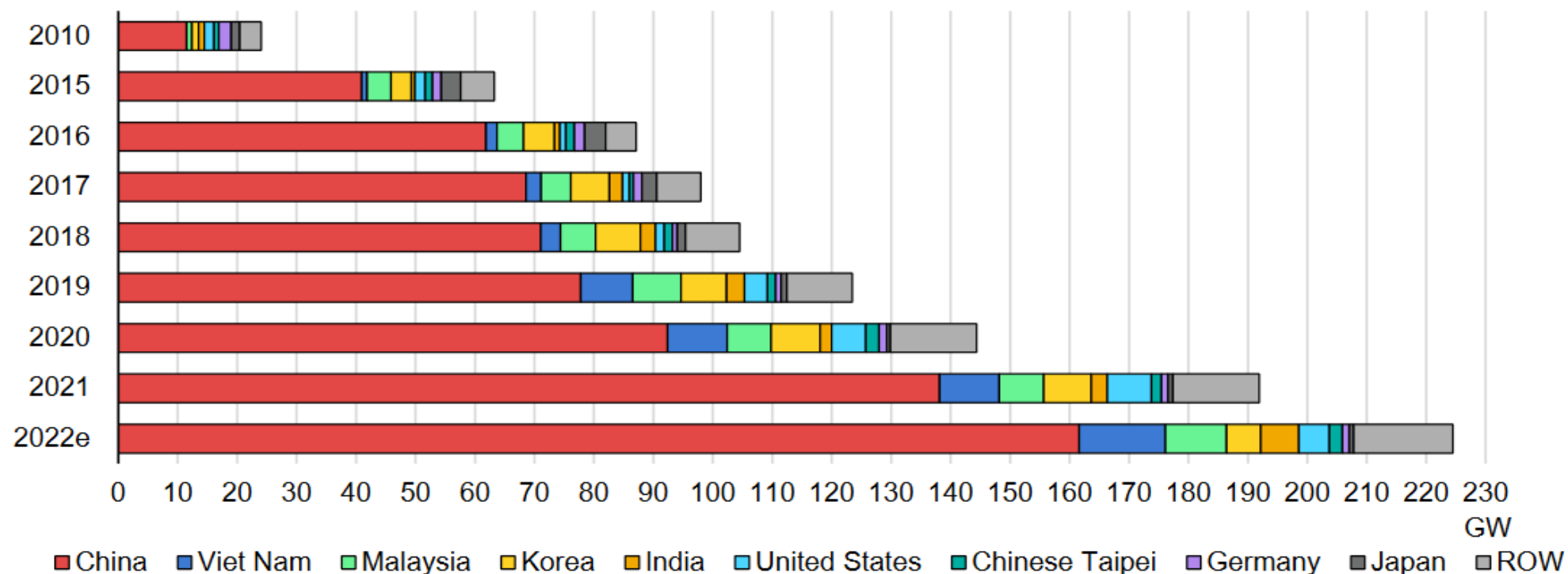
Source: IEA analysis based on BNEF (2022a), IEA PVPS, SPV Market Research, RTS Corporation and PV InfoLink.

Source: IEA 2022, Special Report on Solar PV Supply Chain



Solar PV Modules Production: China the Leader

Global solar PV module production, 2010-2022



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Notes: ROW = rest of world. Values for 2022 are estimates.

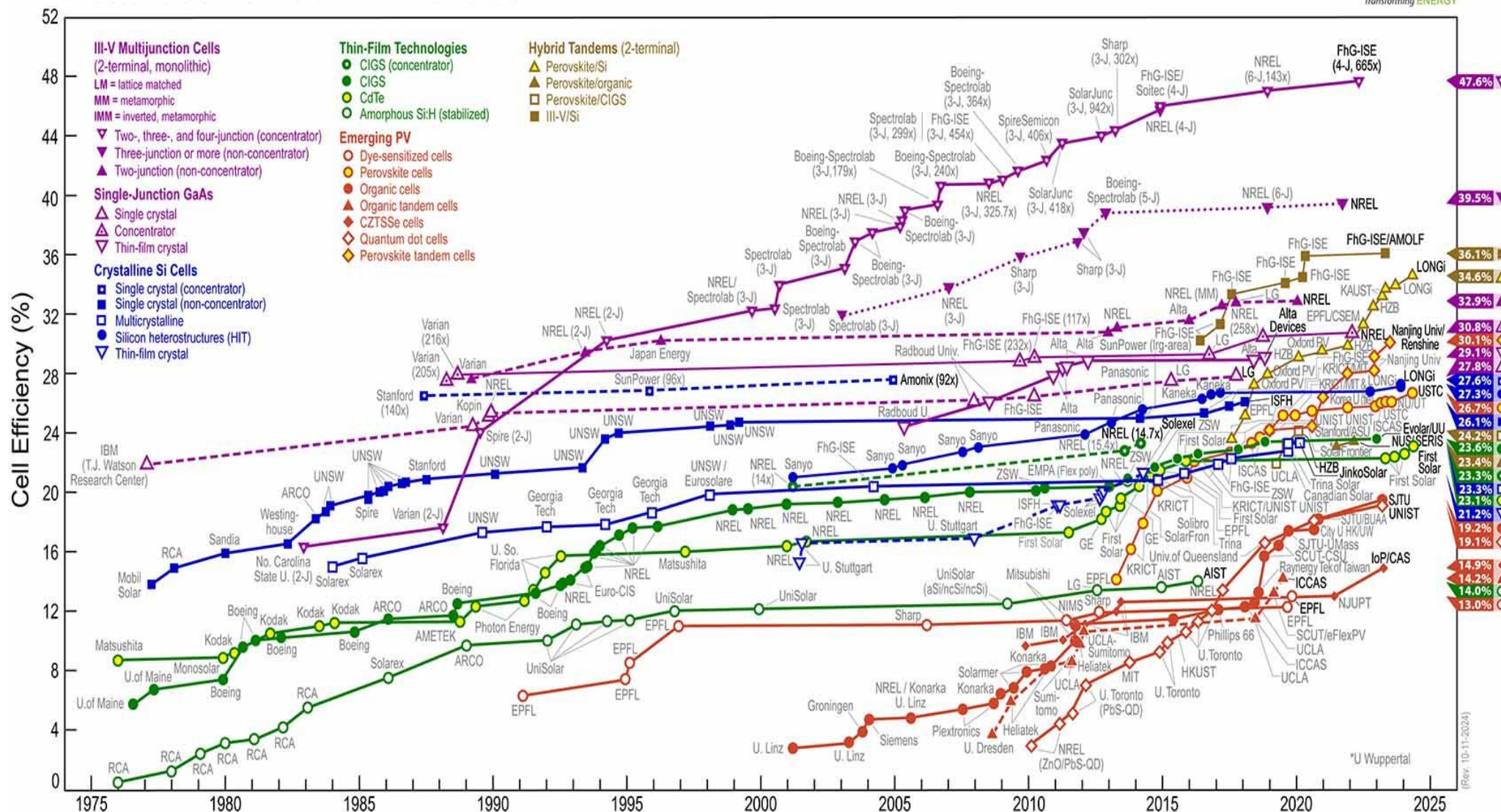
Source: IEA analysis based on BNEF (2022a), IEA PVPS, SPV Market Research, RTS Corporation and PV InfoLink.

Source: IEA 2022, Special Report on Solar PV Supply Chain



History of laboratory records solar cells efficiencies

Best Research-Cell Efficiencies



Solar Panels Efficiency varies vs Temperature

- **Solar panels are generally tested at 25°C. The nominal power is defined on the basis of sunlight power of 1 000 W/m₂.**
- **Excessive heat can reduce the output of a PV system.**
- **As the temperature of the solar panel increases, the voltage output decreases. Impact: - 0,4/0,5 % per 1°C above 25°C.**
- **Solutions exist to reduce those negative effects:**
 - ❖ **Convective air flow can cool the panels**
 - ❖ **Light color material can reduce heat absorption, etc....**



Total involvement in solar technology: Preparing to scale up solar energy

- For nearly 40 years, Total has been working to become a major player in the solar energy business, by building partnerships with innovative start-up's, developing organic growth, promoting research and innovation.
- Some years ago, due to the financial difficulties of the solar energy sector, some of these partnerships failed. In 2011 and 2012, the sector experienced bad results, due to overcapacities, less subsidies and low prices. Since then, the market has been evolving.
- The solar operational branch of TotalEnergies was Sunpower. Sunpower has developed mono-crystalline cells with the best efficiency in the world (24,3% vs around 15% for the best other standards) Due to several difficulties, Sunpower has now ceased all activities.
- Sunpower: design, manufacture & installation of solar cells and systems. In 2011, Total purchased 60% of Sunpower which previously acquired Tenesol (previously owned 100% by Total) Acquisition cost # 1 billion €. Sunpower based in Silicon Valley. Turnover 2009 = 1,5 billion \$, turnover 2014 = 3,0 billion \$, turnover 2018 = 1,7 G\$. TotalEnergies participation down to 32,5%. Since 2019, Sunpower has been facing difficulties and finally ceased all activities in July 2024.
- September 2017: Total partners with EREN Renewable Energy to expand its Renewable Business

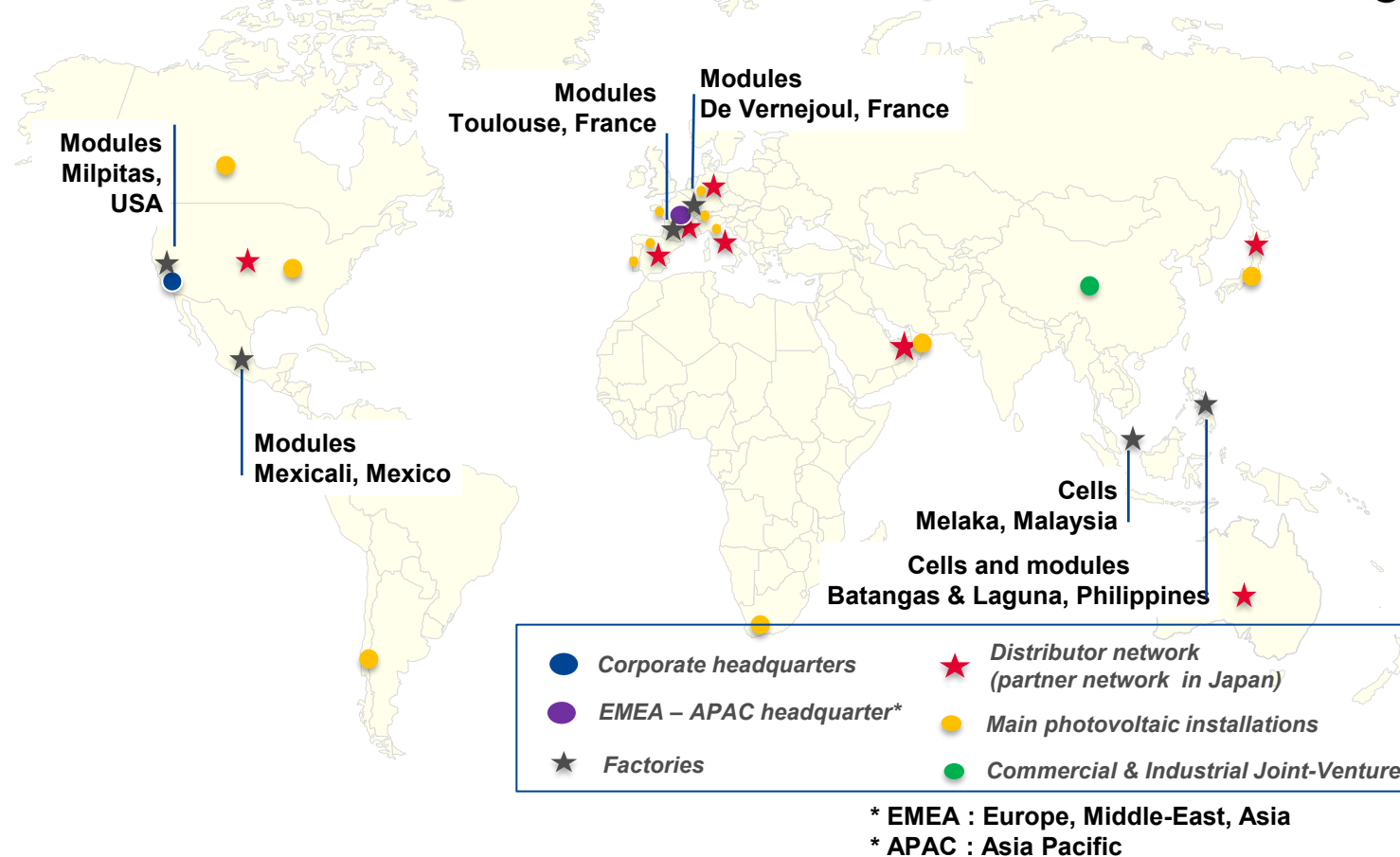


Photovoltech: Solar cells production plant (JV Total/GdFSuez, closed in 2012)



**Initially, TotalEnergies Majority Shareholder in Sunpower.
Due to several difficulties, Supower ceased all activities in 2024**

SunPower had a global international presence



SUNPOWER



**Sunpower, one of the top world solar companies,
with very efficient cells (22.8% yield)**



Sunpower Solar Cells

Compared to conventional modules,

- **Mono Crystalline silicon**
- **Efficiency Ratio: from 21,5 to 24,2% (12 to 15% for the best competitors)**
- **8% more Energy Production (kWh/kWp)**
- **Highly resistant to wear, corrosion, temperatures variations**
- **No light Induced Degradation**
- **High Power at High Temperature**
- **Better Low-Light and Spectral Response**
- **High Performance Anti Reflective Glass**



Some Sunpower (TotalEnergies 60% in 2011, down to 32,5% in 2023) projects

➤ California Valley Solar Ranch:

250 MW, 75 000 solar panels installed on 607 ha. Supply of 100 000 households. Combined with a water saving programme. Start-up: October 2013

➤ Antelope Valley Solar Project (Solar Star):

Sunpower will manufacture, install, operates and maintain a major solar PV facility in Antelope Valley – California.

Contract signed in december 2012 (Solar Star)

Owner: Mid American Renewables (Warren Buffet)

Installed power capacity: 580 MWp on 1 300 ha, 1 720 000 solar panels, will feed 255 000 households

Cost involved: 2,5 billion \$

Construction start: 1st Q 2013

Completion: end 2015

➤ Sunpower in Chile (PV Salvador Project)

Salvador solar farm at Diego de Almagro/Atacama region. 138 ha. Power capacity: 70 MWp. 200 GWh. 160 000 solar panels. Completion: January 2015. 70 000 households powered. Capex = 200 M\$. Electricity price = 120 €/MWh

Additional new projects are starting in Chile.

➤ Since 2019, Sunpower has been facing difficulties. The activity of solar panels fabrication was transferred to Maxeon Solar in 2019. In 2022, TotalEnergies purchased Sunpower industrial & commercial solar activities for 250 M\$. Sunpower ceased all activities in July 2024 and was declared bankrupt in August 2024.



California Valley Solar Ranch



California Valley Solar Ranch

California Valley Solar Ranch, 315 MW dc (250 MW ac), USA



Copyright @ Courtesy of SunPower Corp.

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Solar Star - California

XXL Solar Power Plants



Because solar will partner with oil and natural gas to supply tomorrow's energy, we are focusing on ambitious photovoltaic solar projects today. After starting work on Solar Star in California, we took another step forward in 2013. Together with our affiliate SunPower, a global solar leader and maker of the world's most efficient panels, we were chosen to build and operate several solar power plants around the world, in Japan, South Africa and Chile. The latter will be the largest merchant solar power plant ever built, with a capacity of 70 MWp.



255,000

IS THE NUMBER OF CALIFORNIA HOMES THAT WILL BE POWERED BY SOLAR STAR

Solar Star, California

THE WORLD'S BIGGEST SOLAR POWER PLANT UNDER CONSTRUCTION

21.5%

IS THE AVERAGE CONVERSION EFFICIENCY OF SUNPOWER PANELS, VERSUS A MARKET AVERAGE OF 17%



Solar Star - California

Solar Star, 747 MW dc (579 MW ac), USA



PV Salvador - Chile



PV Salvador - Chile

PV Salvador, 70 MW dc (68 MW ac), Chile



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Solar plant at Nanao/Japan ISE Group/Total/Sunpower



**27 MWp located in Nanao, Japan's Honshu Island, 25 ha
Completed one year after start of construction
ISE (50%), Total (25%), Sunpower (25%)**



Total's Solar Projects in Japan



Al Kharsaa PV Plant - Qatar (1)

- **800 MWp - Photovoltaic plant with bifacial modules (21% efficiency)**
- **Plant Built and Operated by Siraj1 Company - 40 % Marubeni and TotalEnergies, 60 % Siraj Energy (Qatar Energy and QWEC)**
- **Plant divided into 108 block of 288 modules. Trackers to follow the sun path.**
- **2 000 000 MWh produced annually**
- **26 Million tons of CO2 avoided during the 25 years of operation**
- **Location: Al Kharsaa, 80 km West of Doha**
- **Area: 10 Km2. Capacity: # 800 MWp**
- **Construction start-up: 3rd quarter 2020, 2 years construction**
- **Operations start-up: October 2022**



Al Kharsaa PV Plant - Qatar (2)



Efficiency Ratios per area - Some figures

Site	Capacity (MWp)	Cap.Fac. (%)	Generat. (GWh/a)	Area (ha)	Ratio (W/m ₂)	Ratio (kWh/m ²)
California Valley Solar Ranch - California	250	24%	526	607	41	87
Antelope Valley Solar Star - California	580	24%	1219	1300	45	94
PV Salvador - Chile	70	33%	200	138	51	145
Nanao - Japan	27	17%	40	25	108	160
Kamuthi - India	648	17%	965	1000	65	96
Cestas - France	300	13%	350	260	115	135



Sunpower cleaning robot

SunPower cleaning robot, 75% less water required for cleaning



Copyright @ Courtesy of SunPower Corp.

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NOMAD Solar station -TotalEnergies EREN Zhalagash – South Kazakhstan



Photo: J.P. Cordier TPA

NOMAD Solar station -TotalEnergies EREN Zhalagash – South Kazakhstan



83592 Jinko solar PV Modules on 70 ha - 28 MW
Life time of solar panels guaranteed : 25 years

Photo: J.P. Cordier TPA



NOMAD Solar station -TotalEnergies EREN Zhalagash – South Kazakhstan

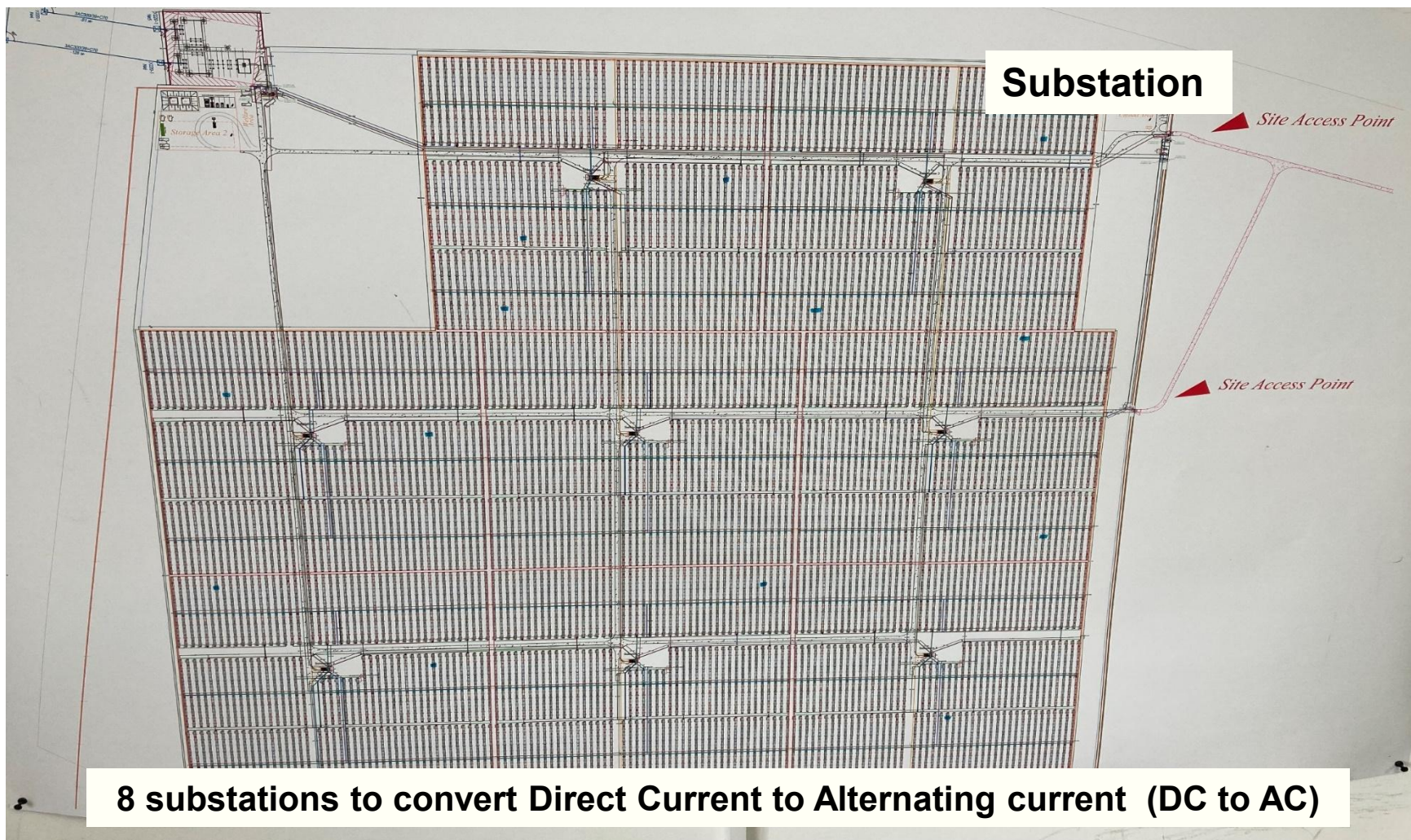
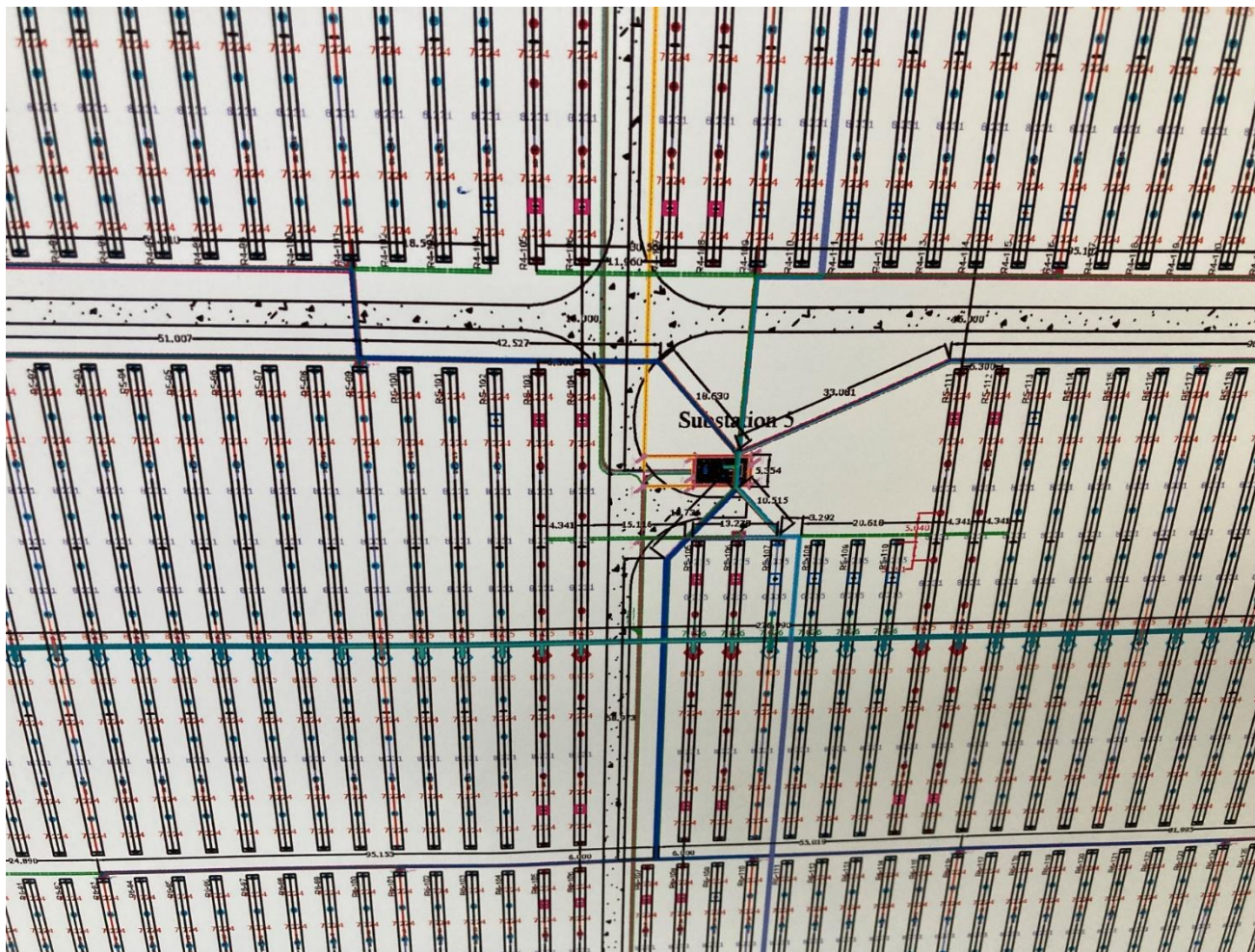


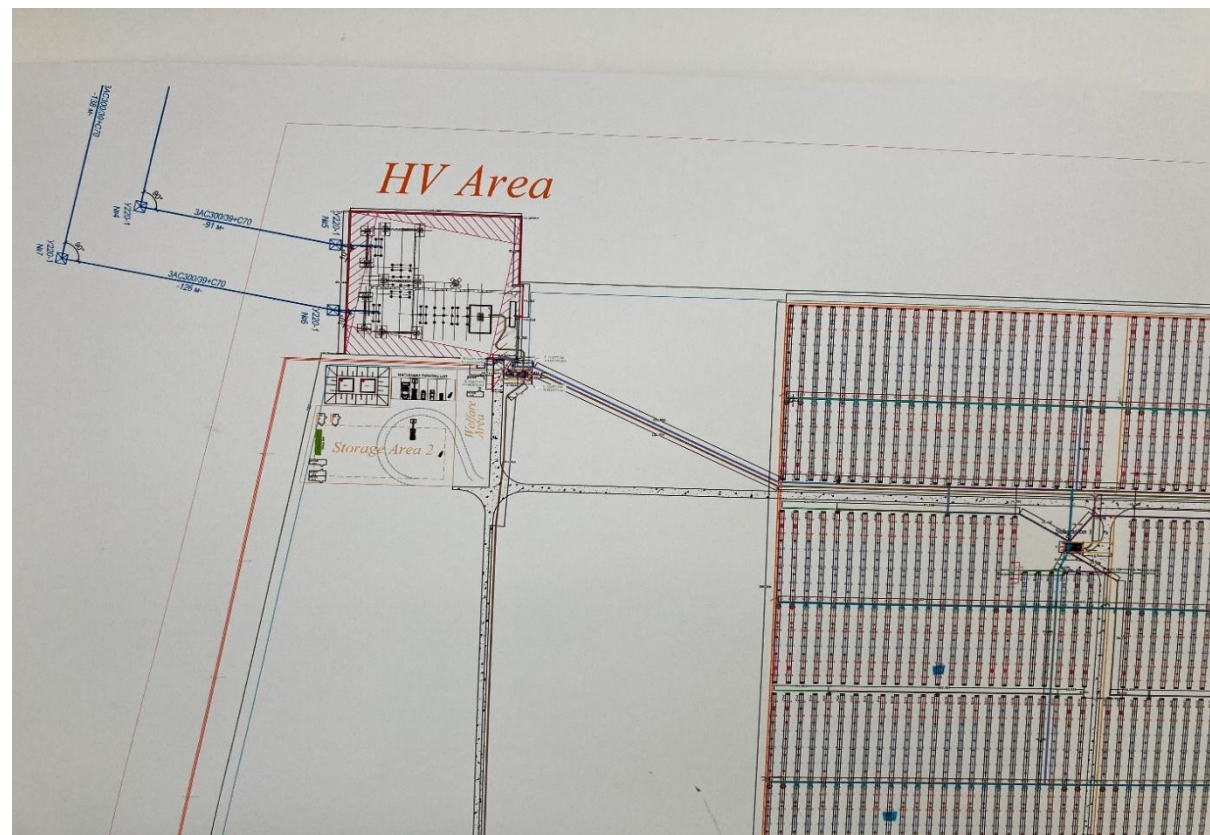
Photo: J.P. Cordier TPA

NOMAD Solar station -TotalEnergies EREN Zhalagash – South Kazakhstan



One substation
Sungrow inverter

NOMAD Solar station -TotalEnergies EREN Zhalagash – South Kazakhstan



Electrical transmission system
Output 220 KV for around 15 000 people- 4 villages

Photo: J.P. Cordier TPA

NOMAD Solar station -TotalEnergies EREN Zhalagash – South Kazakhstan



Solar panels are mounted on “single-axis tracking systems.” They are attached to horizontal poles which run north to south. Throughout the day ,the panels rotate from east to west to follow the sun.

Photo: J.P. Cordier TPA



NOMAD Solar station -TotalEnergies EREN Zhalagash – South Kazakhstan



Snow-depth measurement

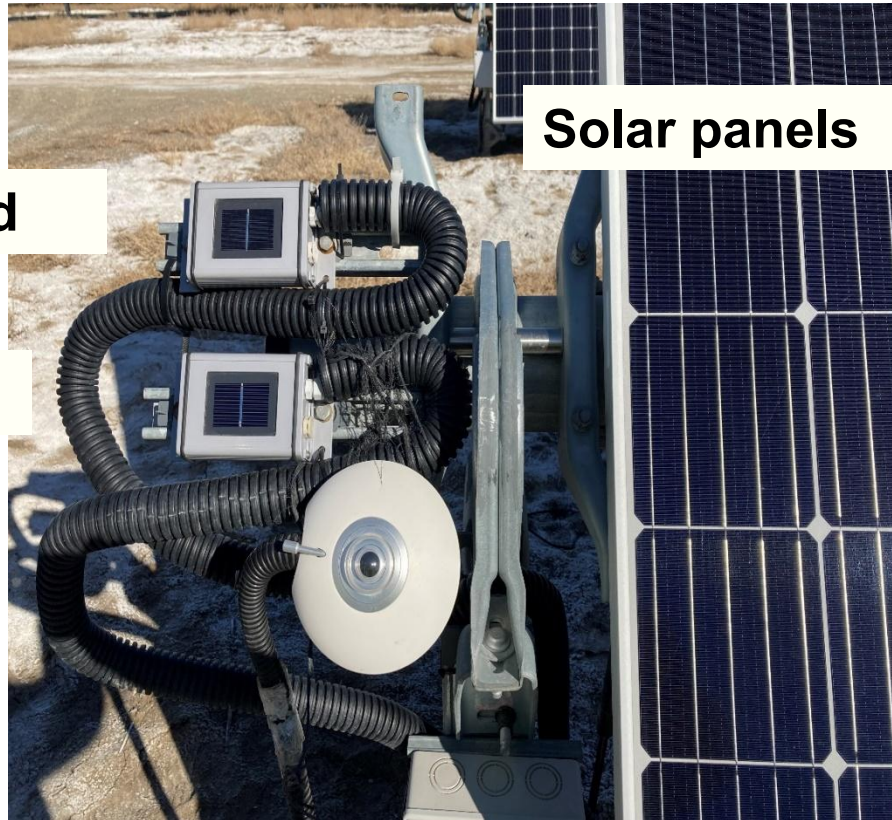
Photo: J.P. Cordier TPA



Wind speed measurement
*Trackers go to stow at 11 m/s. Structure
designed for 47 m/s to 51 m/s*



NOMAD Solar station -TotalEnergies EREN Zhalagash – South Kazakhstan



Dust monitoring system on PV modules.
In case of output difference greater than 3% ,
cleaning up by robots

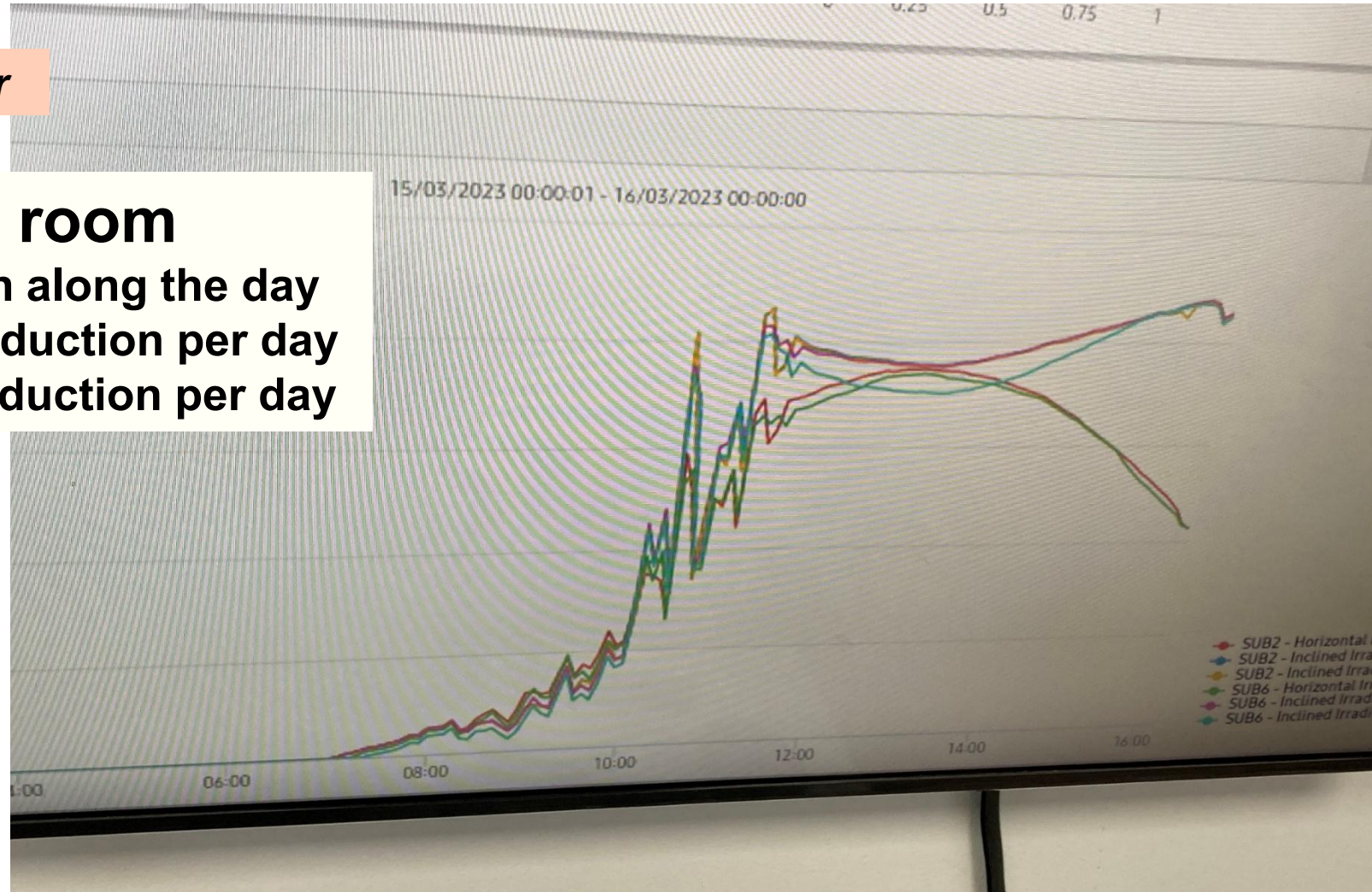
Albedometer : Two pyranometers
measuring both global and reflected solar radiation
(W/m^2). *For future double-sided solar panels*
Albedos of typical surfaces range from about 4 % for fresh
asphalt and 15 % for green grass to 90 % for fresh snow.

NOMAD Solar station -TotalEnergies EREN Zhalagash – South Kazakhstan

Power

Control room

Power generation along the day
Summer: 18 h production per day
Winter: 7 h production per day



Time

Solar panels in China



Concentrated Solar Power (CSP)



Concentrated Solar Power



Solar Tower PS 10 (Spain)
11 MWe – Site area: 550,000 m²
Solar receivers area: 75,000 m²
Solar to power efficiency: 15-18%



**Parabolic Trough
Nevada One**
64 MWe – Site area: 1,4 km²
Solar receivers area: 0,35 km²
Solar to power efficiency: 12-15%

**Dish Stirling
Odeillo (France)**
9 kWe
Solar to power efficiency: 17-20%



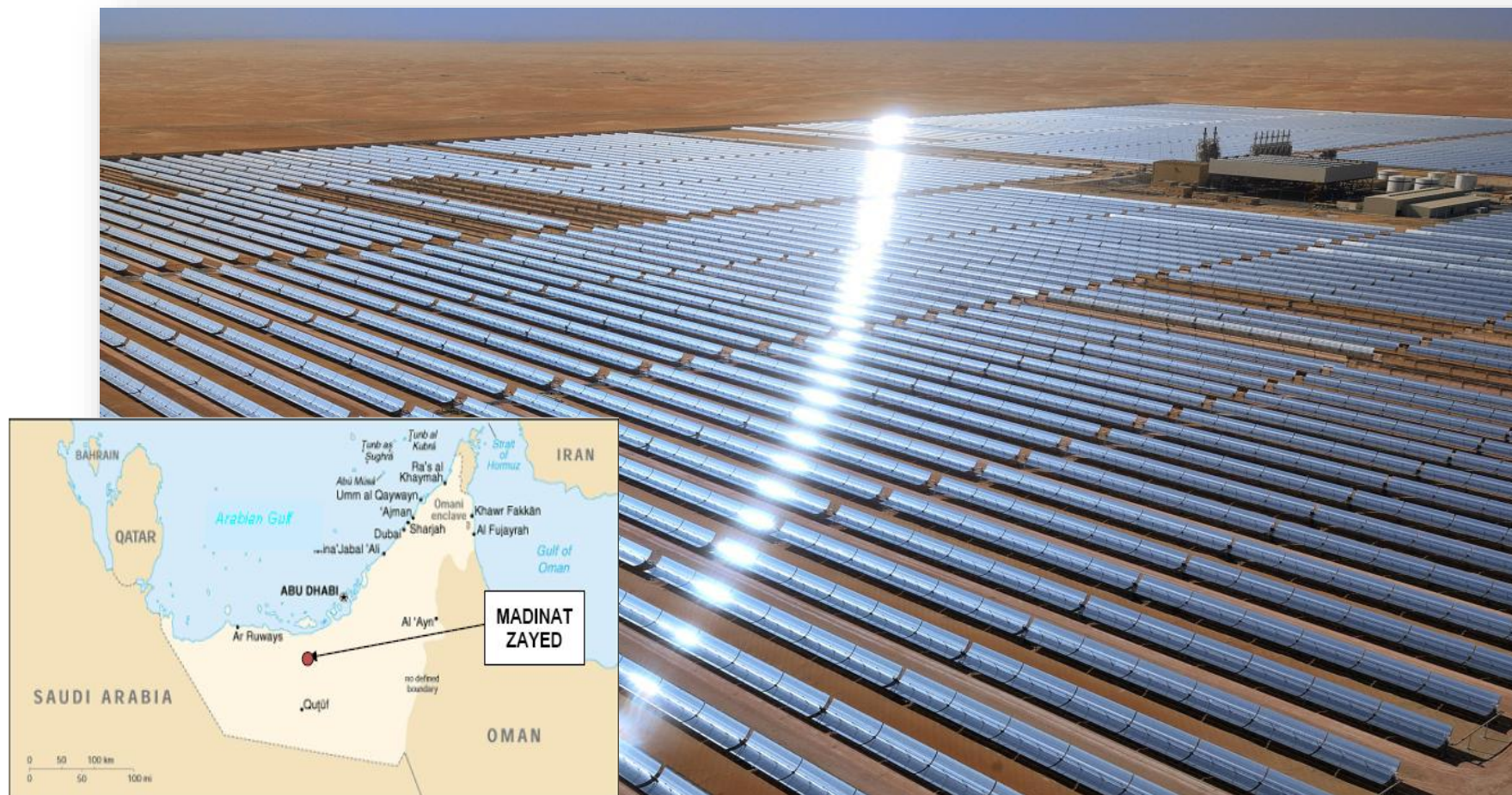
Shams Project Abu Dhabi (1)

- **One of the world largest concentrated solar power plant**
- **Built by a joint consortium of TotalEnergies (20%)/Abengoa Solar (20%) together with Masdar (60%) from 2010 to 2013. Masdar later bought the share on Abengoa**
- **In operation since 2013, it has produced more than 2 000 Gwh of electricity in ten years and offset 1.75 million tonnes of carbon dioxide**
- **Location: Madinat Zayed, 120km SW Abu Dhabi**
- **Area: 450 ha. Capacity: # 110 MW, 768 parabolic collectors, 258 000 parabolic mirrors**
- **Cost: 700 M\$**

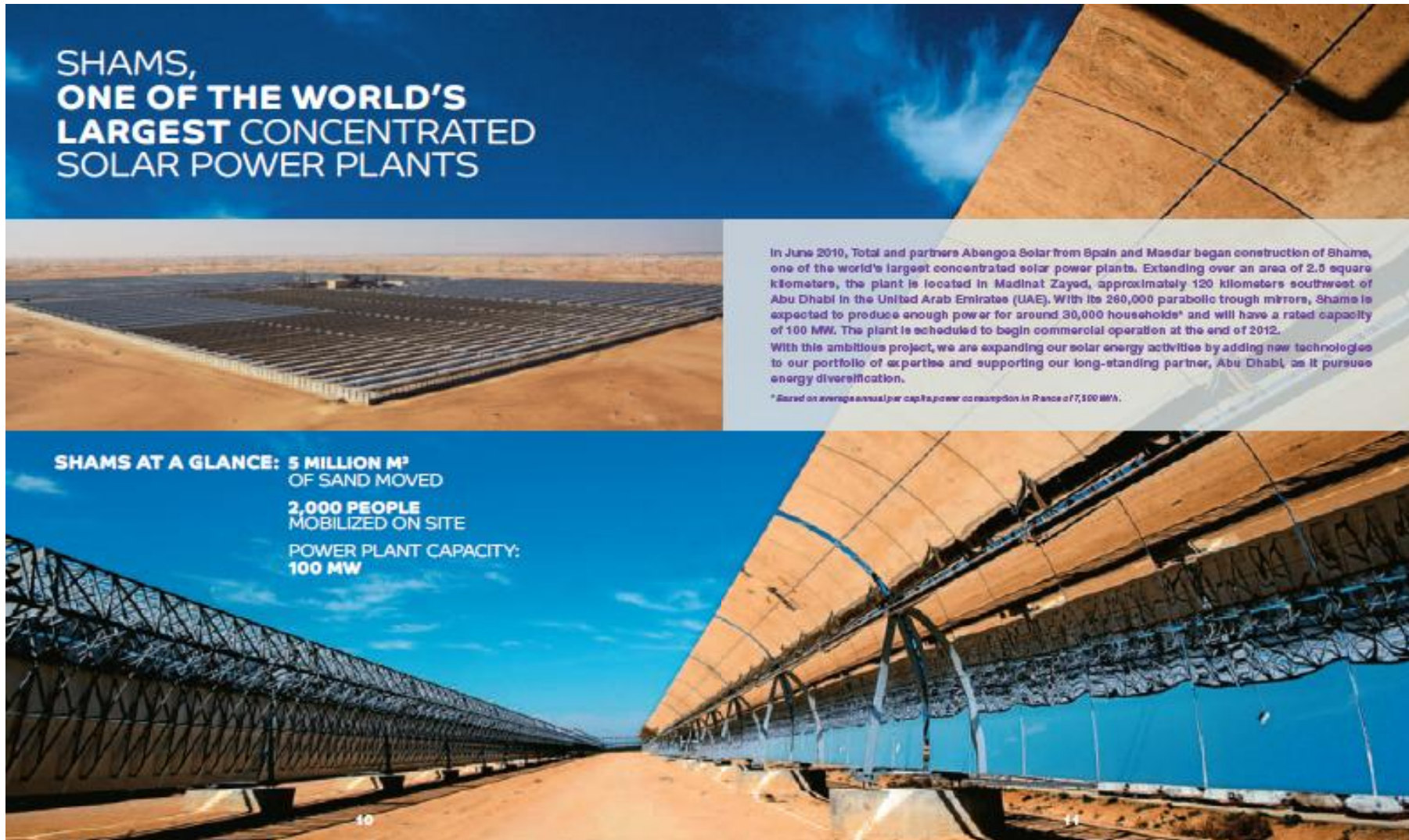


Shams Project Abu Dhabi (2)

The plant meets the electricity demand of 30 000 households



Shams Project Abu Dhabi (3)



**SHAMS,
ONE OF THE WORLD'S
LARGEST CONCENTRATED
SOLAR POWER PLANTS**

In June 2010, Total and partners Abengoa Solar from Spain and Masdar began construction of Shams, one of the world's largest concentrated solar power plants. Extending over an area of 2.5 square kilometers, the plant is located in Madinat Zayed, approximately 120 kilometers southwest of Abu Dhabi in the United Arab Emirates (UAE). With its 260,000 parabolic trough mirrors, Shams is expected to produce enough power for around 30,000 households* and will have a rated capacity of 100 MW. The plant is scheduled to begin commercial operation at the end of 2012. With this ambitious project, we are expanding our solar energy activities by adding new technologies to our portfolio of expertise and supporting our long-standing partner, Abu Dhabi, as it pursues energy diversification.

* Based on average annual per capita power consumption in France of 7,500 kWh.

**SHAMS AT A GLANCE: 5 MILLION M³
OF SAND MOVED
2,000 PEOPLE
MOBILIZED ON SITE
POWER PLANT CAPACITY:
100 MW**



Noor Power Station

Ouarzazate Solar Power Station – Morocco (1)



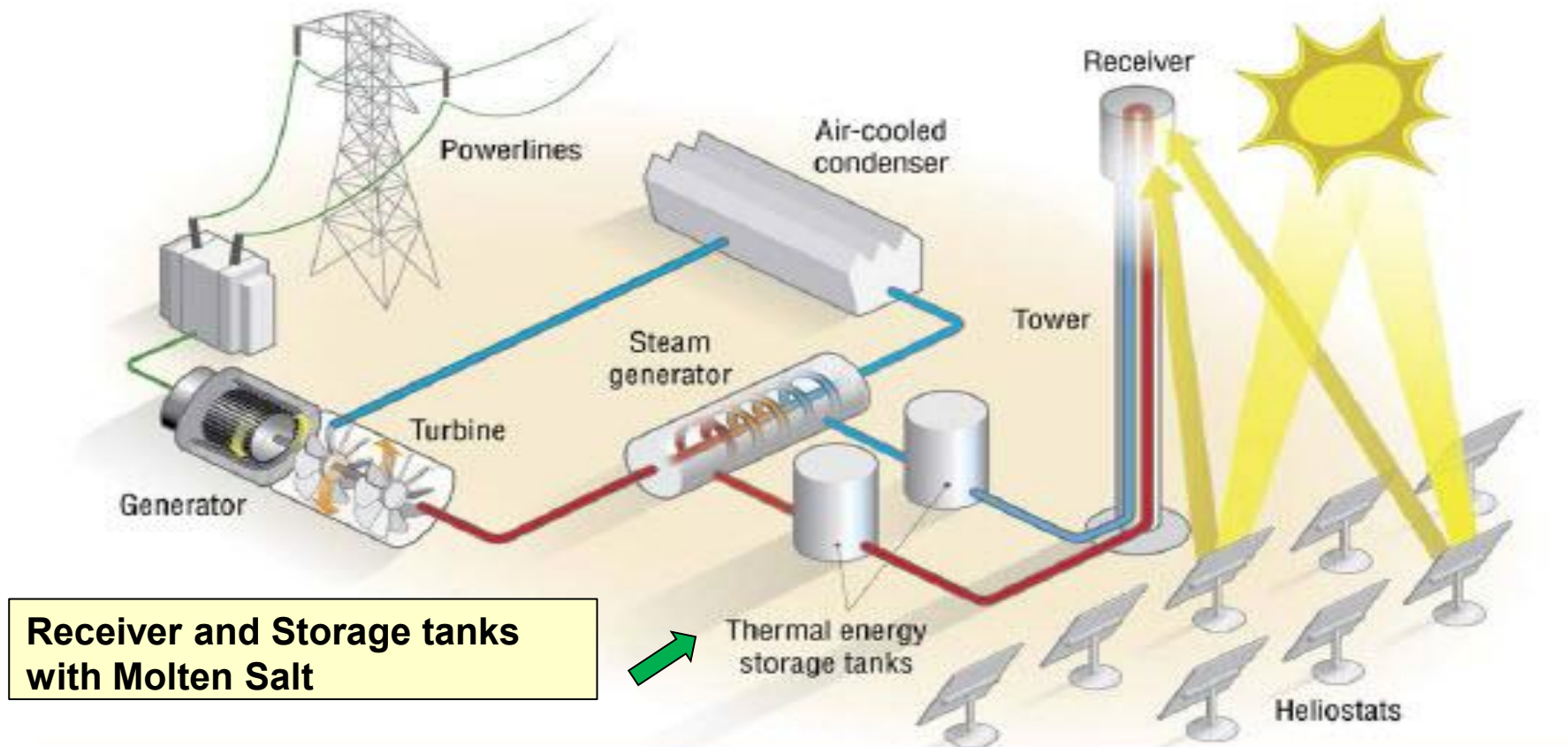
Noor Power Station

Ouarzazate Solar Power Station – Morocco (2)



Noor Power Station Ouarzazate Solar Power Station – Morocco (3)

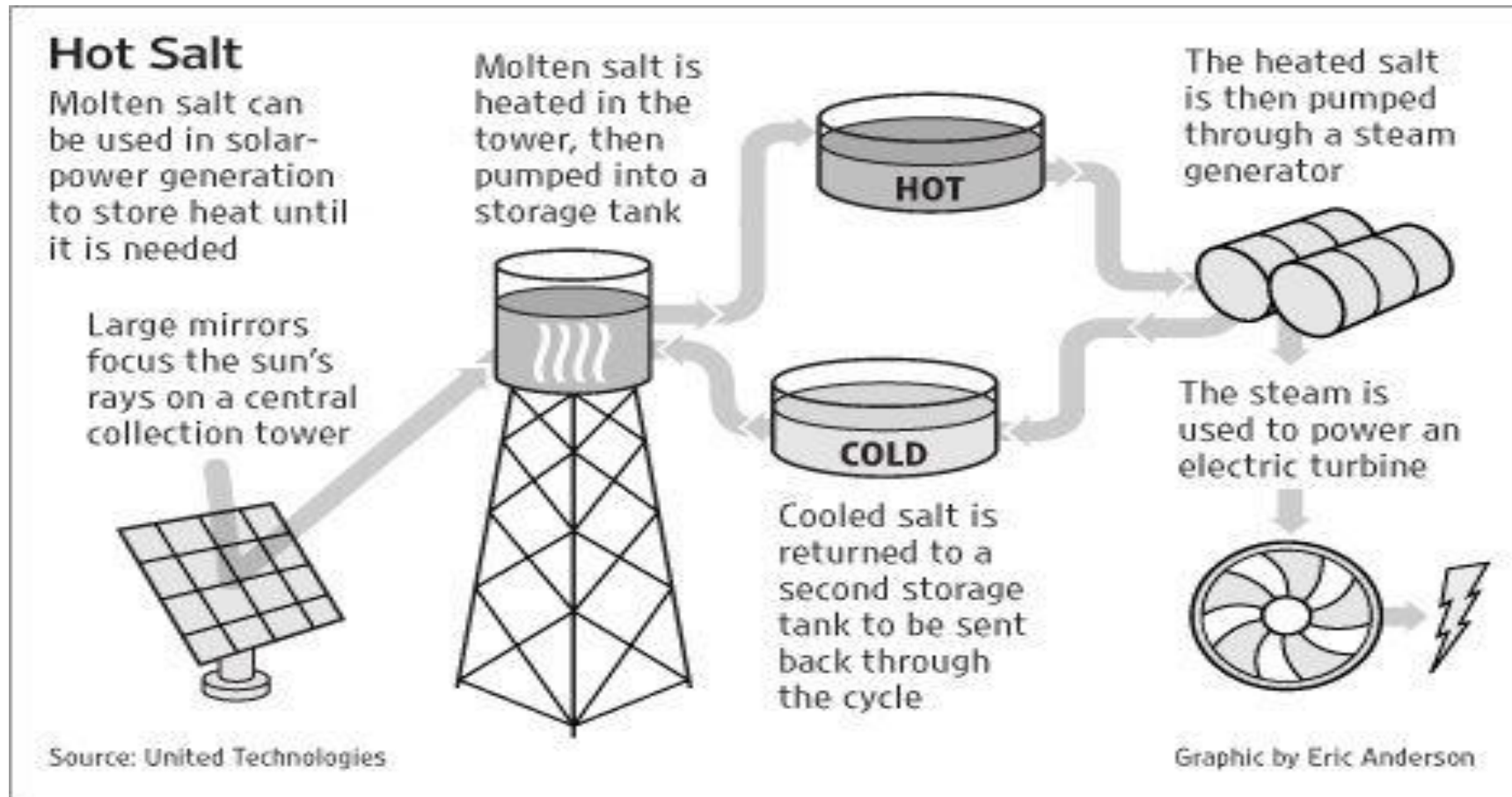
Basic technical principle



Noor Power Station

Ouarzazate Solar Power Station – Morocco (4)

Basic technical principle



Noor Power Station

Ouarzazate Solar Power Station – Morocco (5)

- **Type: CSP**
- **Power: 580 MWp**
- **Energy Storage: Heated Molten Salt**
- **3 phases**
- **Noor 1: Parabolic troughs, 500 000 mirrors, 450 ha, 160 MW, 370 Gwh per year, 3 hours storage, connected to the grid in February 2016, cost = 3,0 G\$**
- **Noor 2: Parabolic troughs, 680 ha, 200 MW, 600 Gwh per year, 7 hours storage, commissioned in January 2018**
- **Noor 3: Parabolic troughs, 550 ha, 150 MW, 500 GWh per year, 7 hours storage, commissioned in March 2018. Since then, several incidents (leaks on the heat transfer network) have reduced production**
- **Noor 4: PV Power Station Project, 70 MW**
- **Partners: TSK-Acciona-Sener, ..., MASEN (Morocco Agency for Solar Energy)**
- **Operator: ACWA Power**
- **The project has experienced additional problems in connection with access to water and drought in the country.**

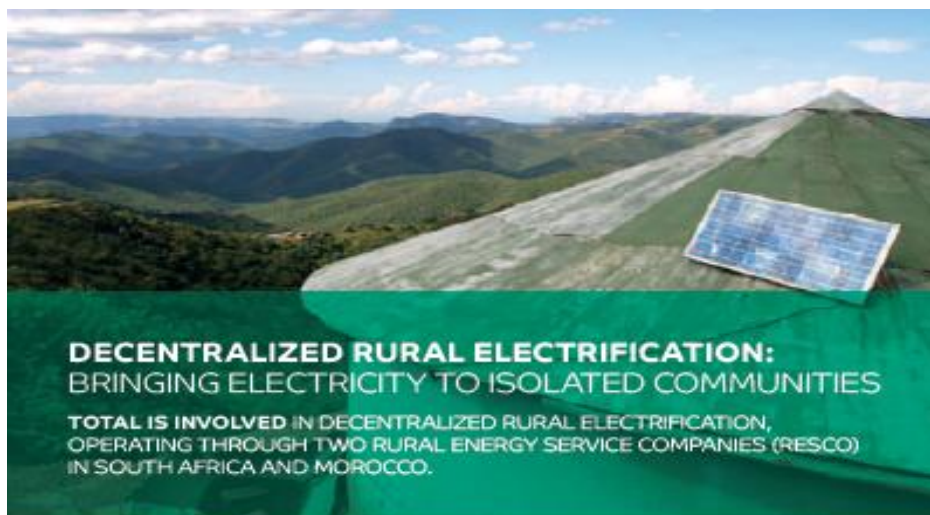


Characteristics of some typical Solar Energy Projects

Project	Type	Location	Power (MW)	Production (GWh)	CF (%)	Nb of solar panels	Area (ha)	Households supplied	Capex (M\$)	Start-up
California Valley Solar Ranch	PV	California	250	675	31	75 000	800	100 000	1 600	2013
Solar Star	PV	California	580	1685	33	1 720 000	1300	255 000	2 500	2015
Salvador	PV	Chile	70	200	33	160 000	138	70 000	200	2015
Nanao	PV	Japan	27	na	na	80 000	25	9 000	na	2017
Miyagi Osato	PV	Japan	52	na	na	116 000		na		2021
Al-Kharsaah	PV	Qatar	350 + 450	na	na	2 000 000	1000	na	Phase 1 470	2022
Boulouparis	PV + Storage	Nouvelle Calédonie	11 16	16	17	43 200 58 000	17 35	5 400 21 000	50	2017
Shams	CSP	Abu Dhabi	110	210	22	258 000	250	30 000	700	2013
Noor Ouarza. 1	CSP + Storage	Morocco	160	370	26	500 000	480	na	3 000	2016
Noor Ouarza. 2	CSP + Storage	Morocco	200	600	34	na	680		810	2018
Noor Ouarza. 3	CSP + Storage	Morocco	150	500	38	na	550	na	645	2019
Noor Ouarza. 4	PV	Morocco	72	120	19	na	137	na	85	2019
Noor Midelt Several phases	CSP PV	Morocco	600 1000	na	na	na	3 000	1 000 000 people	3700	Phase 1 2022



Actions developed by Total



IN SOUTH AFRICA

KwaZulu Energy Services (KES) was created in 2002 by EDF (50%), Total (35%) and Calulo (15%) to implement a decentralized rural electrification program based on solar energy in South Africa. By mid-2012, around 20,000 households, had been supplied with individual photovoltaic solar kits. KES is continuing its growth and plans to install another 30,000 individual solar systems over the next four years. LPG bottles from Total Gaz are distributed for back-up supply.



IN MOROCCO

Temasol, created in 2002 by Teneosol, EDF and Total, has equipped nearly 25,000 households, representing around 180,000 people. The company is now focusing on maintenance of installed photovoltaic systems, including replacement of defective and end-of-life components. Development avenues include photovoltaic installations for telecommunication relays, drinking water pumping stations and grid-connected solutions.



Promoting the use of PV on industrial facilities



SOLAR PERGOLA AT THE LACQ SITE.

TOTAL SITES, AMBASSADORS FOR PHOTOVOLTAIC POWER

TOTAL IS INTEGRATING PHOTOVOLTAIC SOLAR SOLUTIONS INTO SOME OF ITS EXISTING INDUSTRIAL AND COMMERCIAL INFRASTRUCTURE.

TOTAL GAS STATION IN LE HAVRE.



IN FRANCE, THE FIRST SITES TO BE EQUIPPED IN 2010 AND 2011 WERE THE LACQ COMPLEX AND THE SCIENTIFIC AND TECHNICAL CENTER (CSTJF) IN PAU, BOTH IN THE SOUTHWESTERN REGION OF THE COUNTRY. SOLAR PANELS WERE ALSO INSTALLED AT SOME TEN SERVICE STATIONS.



FACADE OF THE CSTJF BUILDING IN PAU.

The Pau site has a production capacity of 230 MWh/year and a land footprint of about 2,400 square meters of solar panels. The Lacq site's 4,460-square-meter footprint has a production capacity of around 410 MWh/year.

Total intends to promote the installation of SunPower rooftop solar panels at service stations around

the world, within its existing network and especially at new stations. The panels, which can be installed on shop roofs or integrated in canopies, will offer annual production capacity of 35-50 MWh depending on the geographic location.

Around 20 new Total service stations should be equipped in 2013, most of them in Europe and Africa.

9



R&D necessary to cut costs



SOLAR R&D: INVESTING TO IDENTIFY THE MOST EFFICIENT TECHNOLOGIES

SOLAR ENERGY R&D FOCUSES PRIMARILY ON OPTIMIZING CELL PRODUCTION, THE KEY LINK IN THE PHOTOVOLTAIC CHAIN.



In March 2012, Total, EDF, the French National Center for Scientific Research (CNRS) and Ecole Polytechnique, associated with Air Liquide, Horiba Jobin Yvon and Riber, announced the creation of IPVF, one of the five largest centers worldwide conducting research into new generation photovoltaic solar systems. Already active, the Institute will be based at the Paris Saclay Campus by 2015. It will eventually bring together close to 150 researchers, lecturers and students.



The objectives are to reduce costs more quickly, increase the conversion efficiency of existing and future components, and expand applications. This process marshals the wide array of expertise available across Total, in close collaboration with leading science and research organizations. Total has signed a number of partnership agreements recently with globally recognized research centers, including:

LAAS: (Laboratory for Systems Analysis and Architecture - Toulouse, France) to enhance the efficiency of photovoltaic modules using a systemic approach.

IMEC: (Interuniversity MicroElectronics Center - Louvain, Belgium) to decrease the amount of silicon needed for cells and improve their efficiency.

LPICM: (Interface and Thin Film Physics Laboratory - Saclay, France), a joint research facility of the French National Center for Scientific Research (CNRS) and the Ecole Polytechnique engineering school with a combined team working on crystalline silicon thin film technology.

CUTTING COSTS ON STORAGE

Solar energy is intermittent. To allow the broadest possible use, efficient solutions are needed to store this energy and ensure it is available when needed. A five-year, \$4-million contract signed with the Massachusetts Institute of Technology (MIT) in 2008 will help our researchers develop a highly efficient, low-cost, long-life battery. In late 2010, encouraged by the project's very promising results, the partners decided to create a start-up, LMB Corp. (Liquid Metal Battery Corporation), to develop these grid-scale energy storage systems.

7



Awango by Total: Access to electricity to low-income communities



Economique

Les lampes solaires Awango vous éclairent correctement et à moindre coût. Plus besoin de piles ou de pétrole, le soleil devient votre source d'énergie !



Durable

La technologie des lampes solaires Awango respecte l'environnement et vous offre une source de lumière qui facilite votre quotidien et éclaire votre avenir.



Sûr

La simplicité d'utilisation des lampes solaires Awango vous permet de disposer d'un éclairage sans danger pour vos enfants et vos maisons.



Mobile

Fiables et pratiques, les lampes solaires Awango sont équipées de poignées intégrées pour faciliter leur utilisation en situation de mobilité.



Solaire

Durant la journée, en exposant simplement les panneaux solaires de votre lampe aux rayons du soleil, vous la rechargez. La nuit, elle vous éclaire.



Garantie

Sélectionnées et distribuées pour vous par Total, les lampes Awango sont garanties 1 an à partir de la date d'achat.



Charge

Le modèle S 250 Dilight permet également de recharger vos téléphones portables !

\$10 - d.light

LAMPE SOLAIRE
PORTABLE

Eclairage



- Lampe très solide et 3 à 5 fois plus lumineuse qu'une petite lampe à kérosène.
- Durée d'éclairage pour une journée de charge : entre 4 et 8 heures selon l'intensité choisie.
- Panneau solaire intégré.
- Le produit fonctionne dès la vente sans initialisation. L'installation ne nécessite aucun outil.



\$250 - d.light

LAMPE SOLAIRE
PORTABLE

*Eclairage
et recharge de téléphone.*



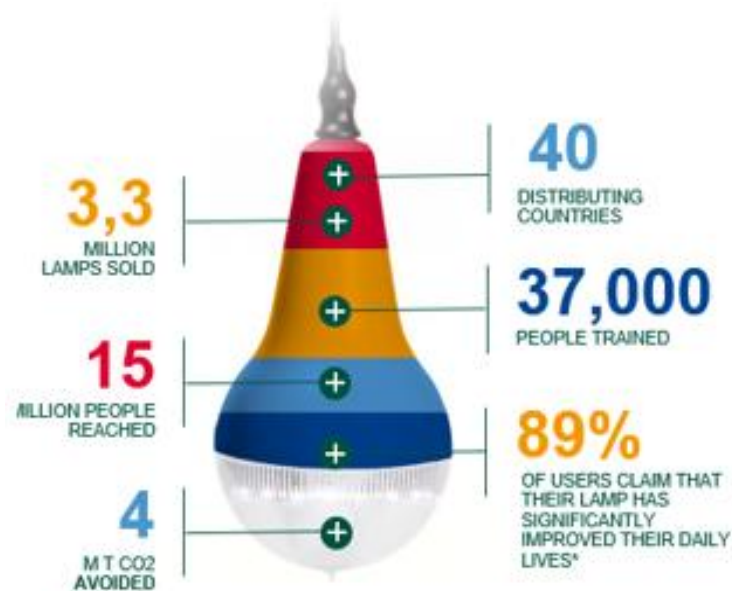
- Durée d'éclairage pour une journée de charge : entre 4 et 12 heures selon l'intensité choisie.
- Panneau solaire externe livré avec un câble de 3m.
- Temps nécessaire pour une recharge complète d'un téléphone basique : entre 2 et 3h. L'offre inclut 6 connecteurs compatibles avec les téléphones portables les plus courants sur le marché.
- Le produit fonctionne dès la vente sans initialisation. L'installation ne nécessite aucun outil.



Total access to Energy Solutions

OUR GOAL: Solar Lamps - To benefit 25 million people by 2025

OUR ACHIEVEMENTS Today



Since 2010, development of a range of innovative and decentralized solutions, meeting the energy needs of people in emerging countries while contributing to the fight against climate change.



Total access to Energy Solutions

OUR GOAL: Solar Lamps - To benefit 25 million people by 2025



- ◆ Since 2010, more than 3.5 million solar lanterns and kits have been distributed in 40 countries via distribution channels involving social entrepreneurs and non-governmental organizations (NGOs).
- ◆ Fitted with accessories such as mobile phone chargers, radios and fans, these solar solutions are genuinely improving the daily lives of more than 15 million people.



Sunpower supplier of Solar Impulse



Industrial Partnerships – Total involvement

Total Energy Ventures: Total's Affiliate in charge of Capital-Risk and Start-ups development.

Off Grid Electric: based in San Francisco, development of solar systems coupled with batteries connected to LED lamps, phone chargers and small electric equipments. First market objective: 1 million clients in Tanzania.

Powerhive: micro networks fed with solar energy stored in batteries, development of local distribution network in Kenya.



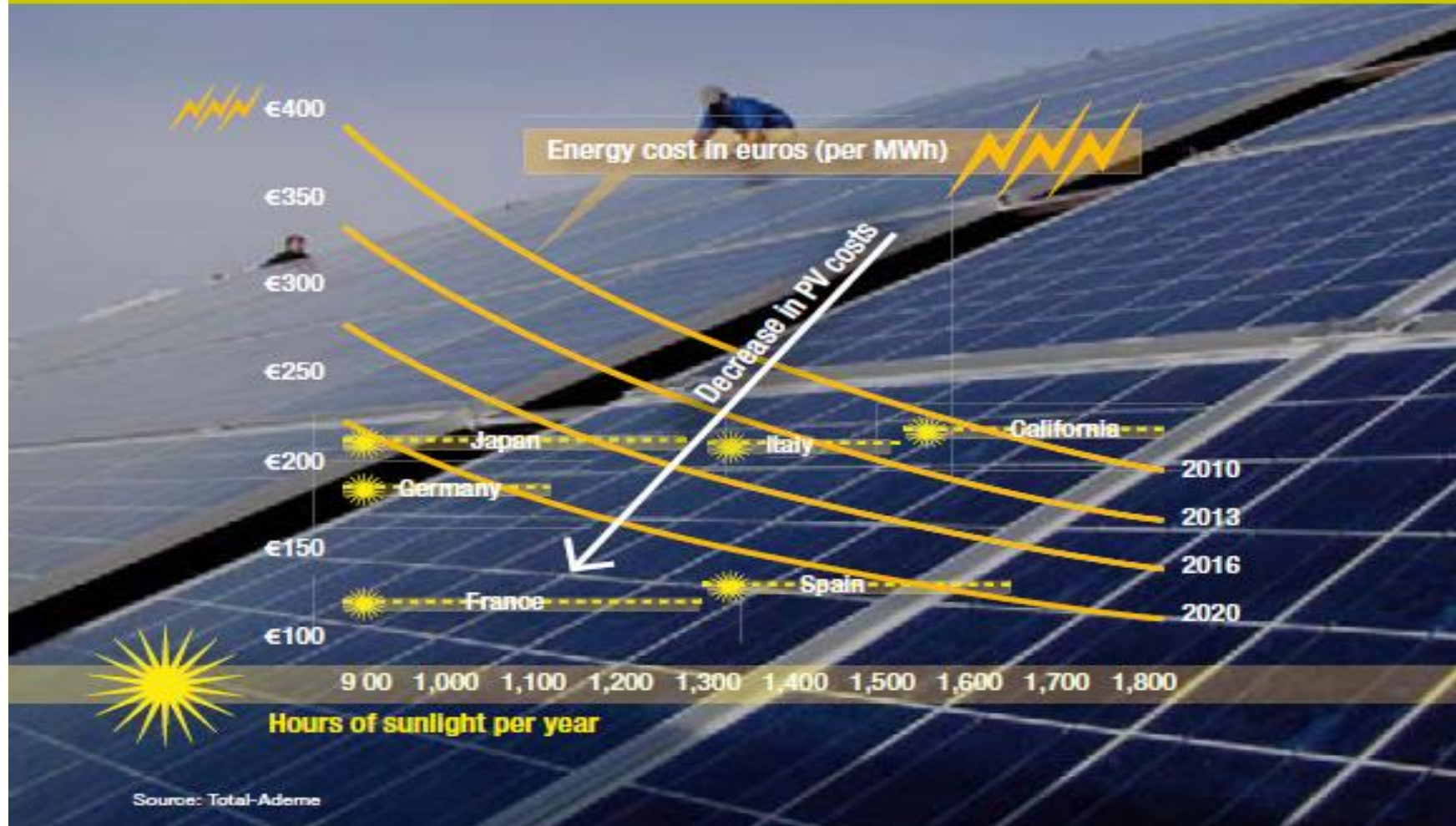
3-3

Solar economics



SOLAR KWH SHOULD BE COMPETITIVE BY 2010 IN SOME REGIONS OF THE WORLD

Illustrative chart - Vision 2010

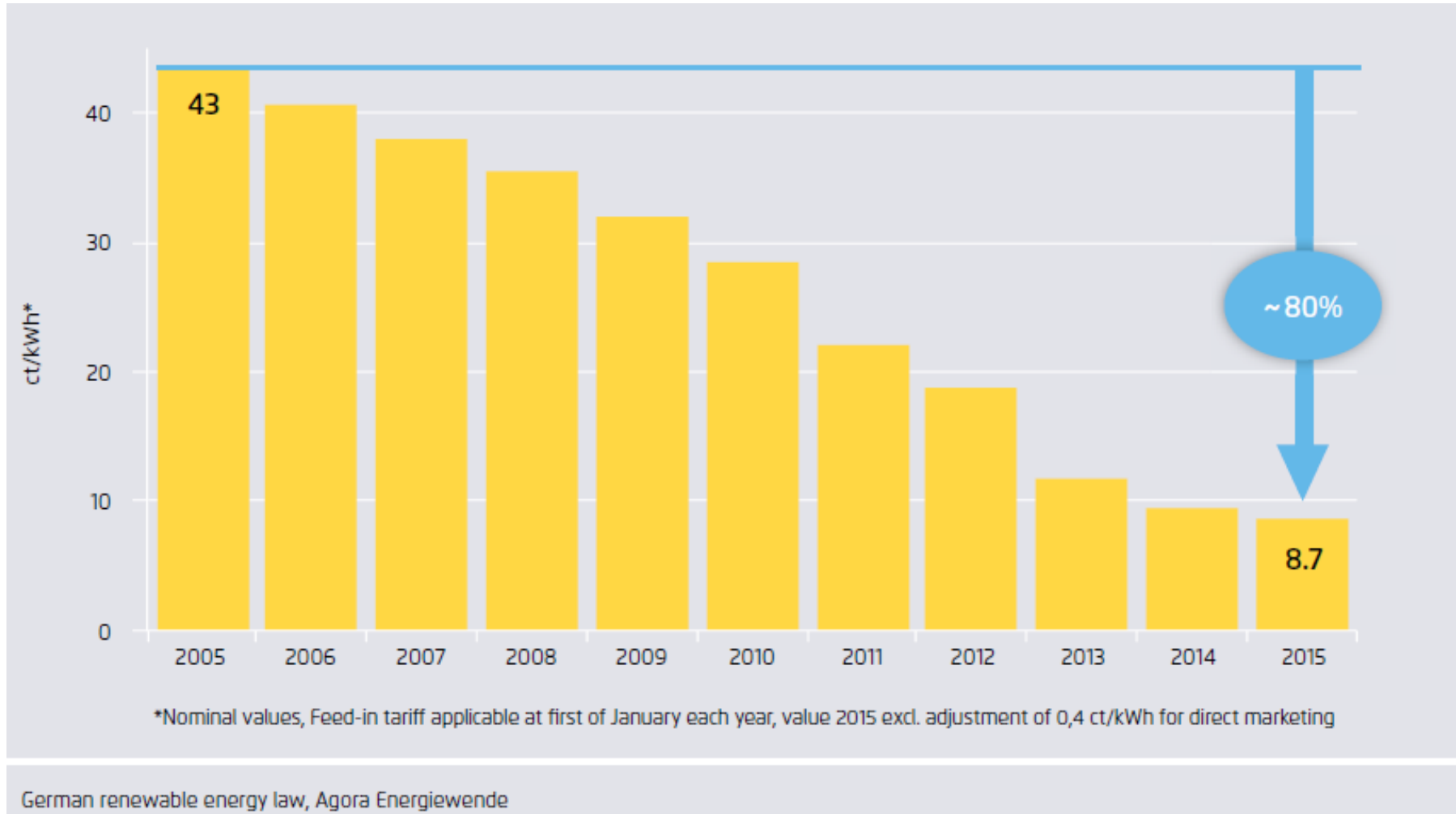


Reminder - Solar Energy – A German vision from 2015
Drastic cost decrease upon time



Solar Energy – A German vision

Drastic cost decrease upon time

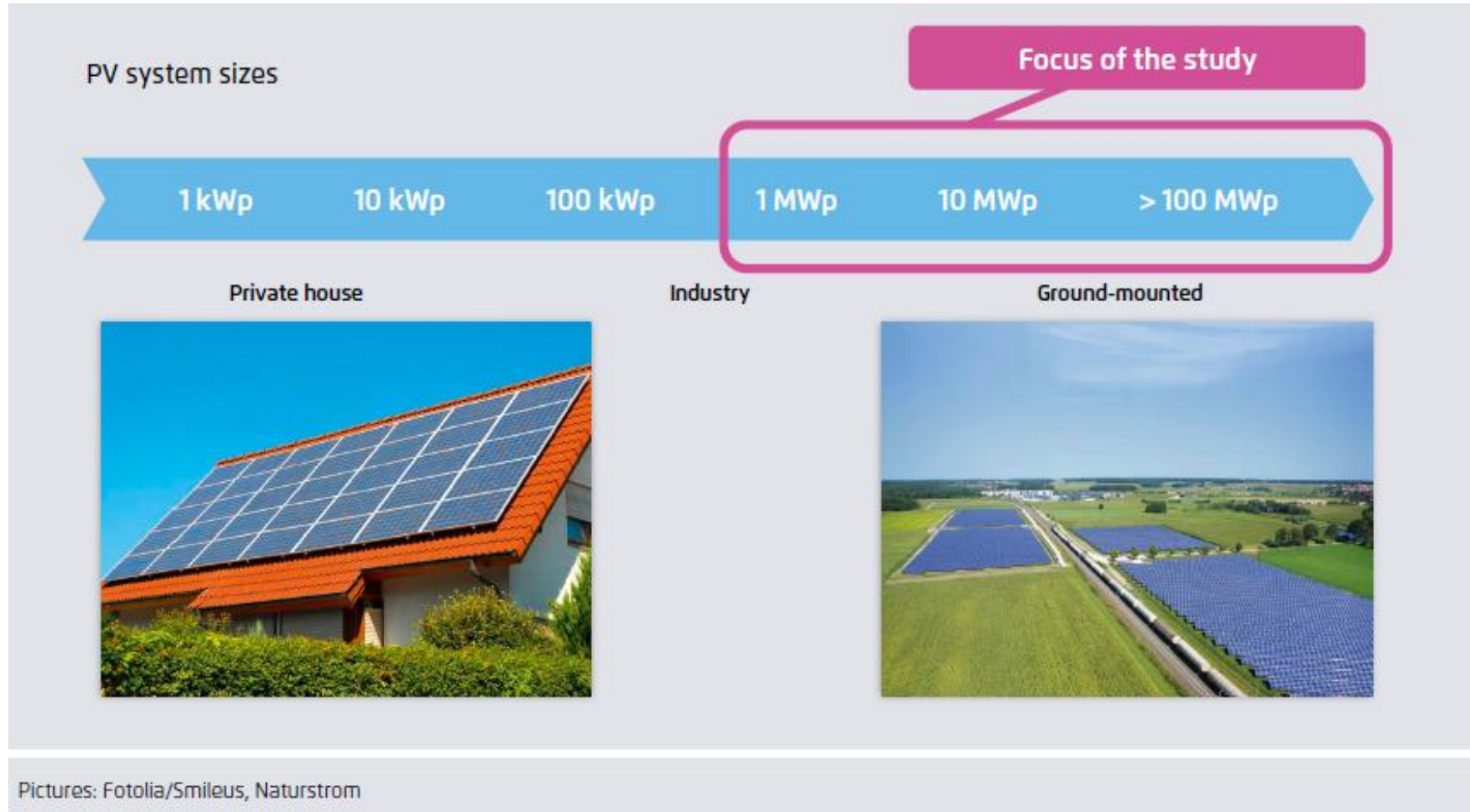


Source: Fraunhofer Agora Energiewende 2015



Solar Energy – A German vision

Drastic cost decrease upon time



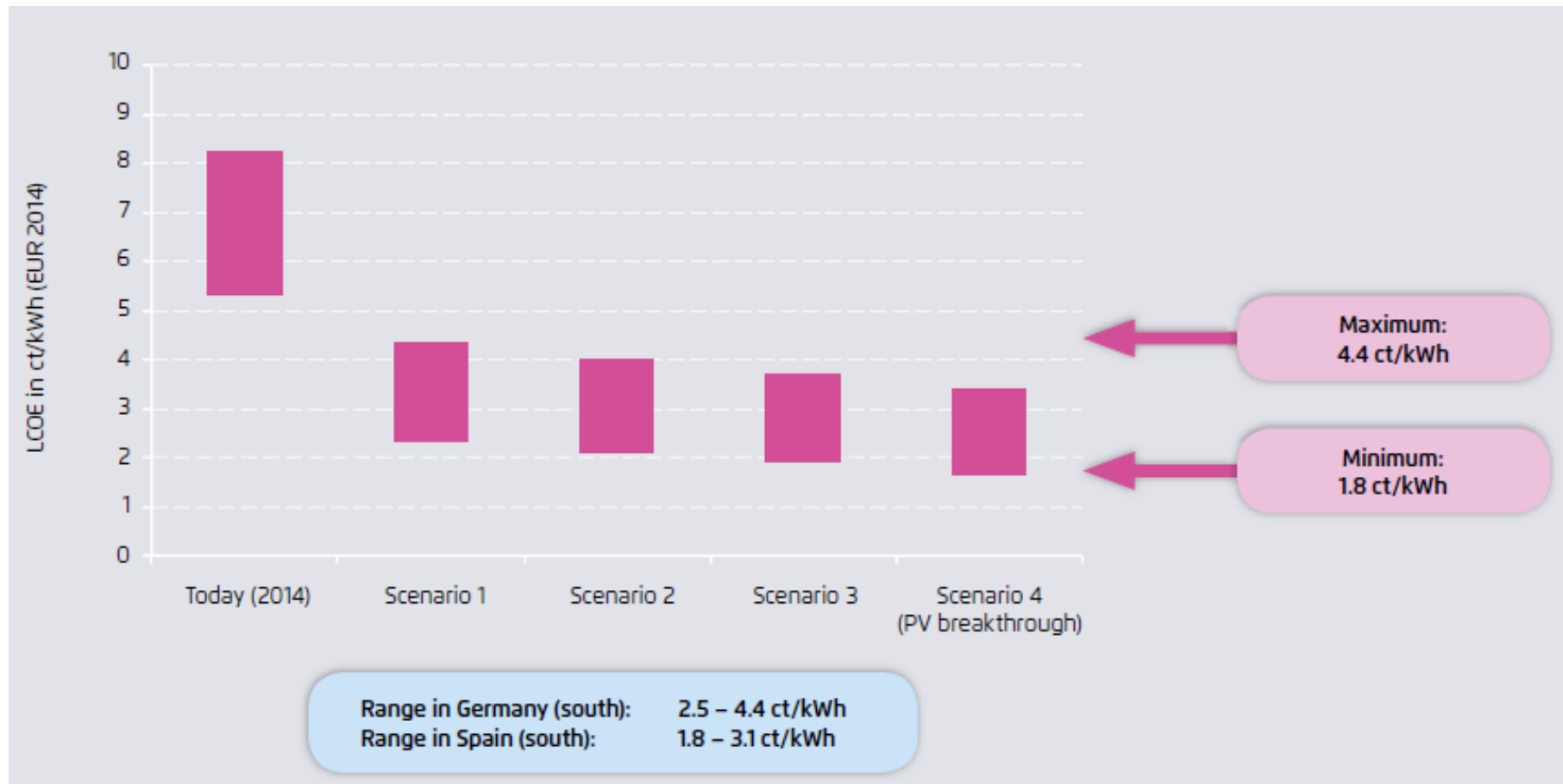
Source: Fraunhofer Agora Energiewende 2015



Solar Energy - A German vision - Drastic cost decrease upon time

Ground-mountain PV systems today & in 2050

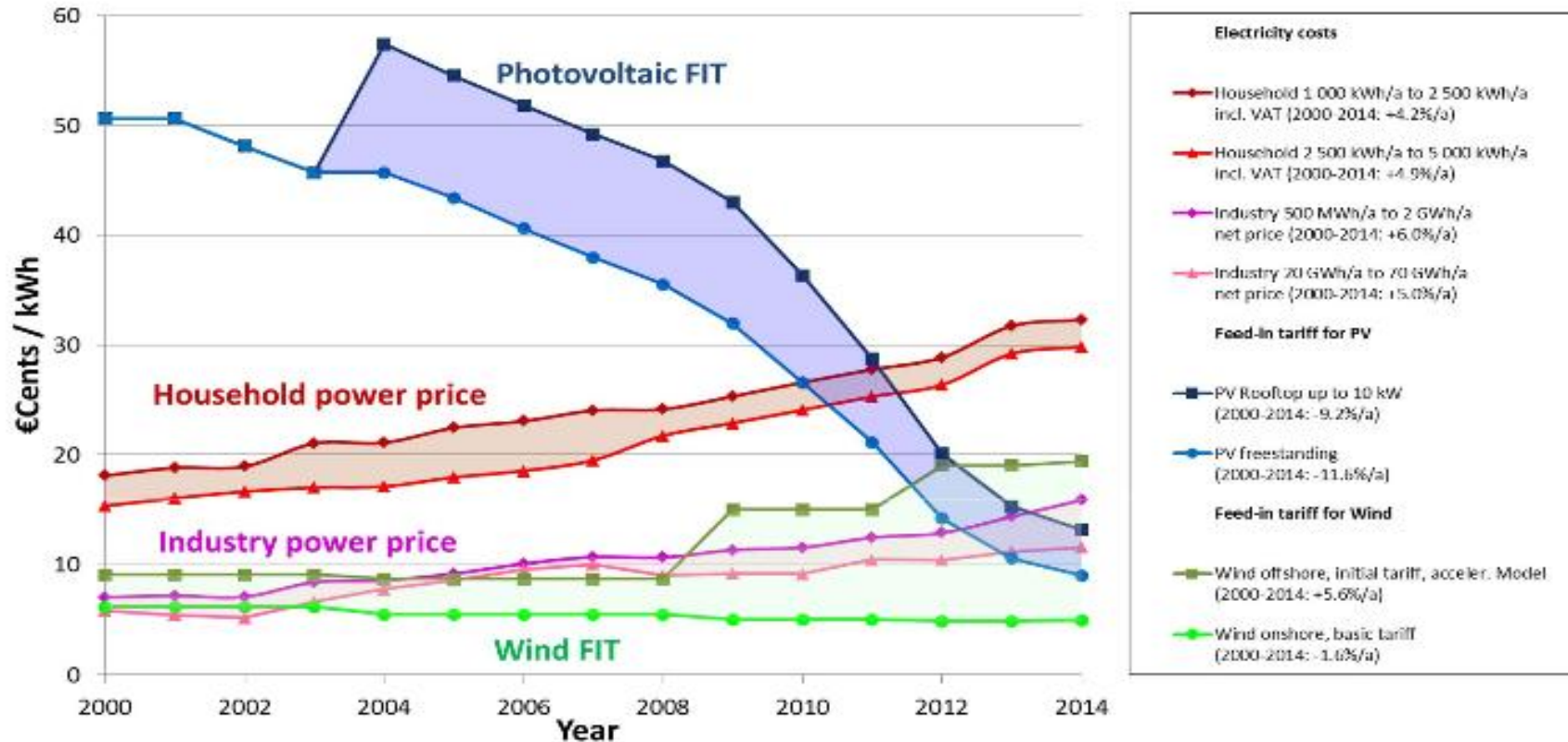
Southern Germany to southern Spain



Source: Fraunhofer Agora Energiewende 2015



Electricity costs and Feed-in-Tariffs (FIT) in Germany – Drastic decrease of the costs



Data: BMU, EEG 2014 and BMWi Energiedaten. Design: B. Burger - Fraunhofer ISE, Update: 16.10.2015

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© Fraunhofer ISE

Fraunhofer
ISE

Source: Fraunhofer ISE

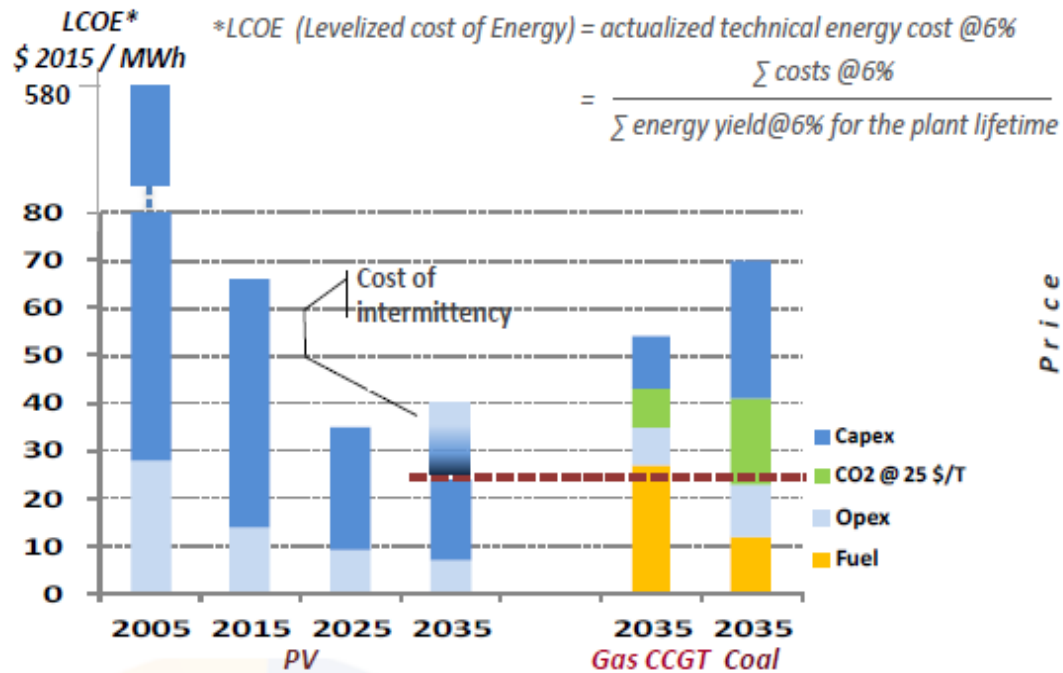
371

TPA Toolbox Energy Book 7 – Renewables

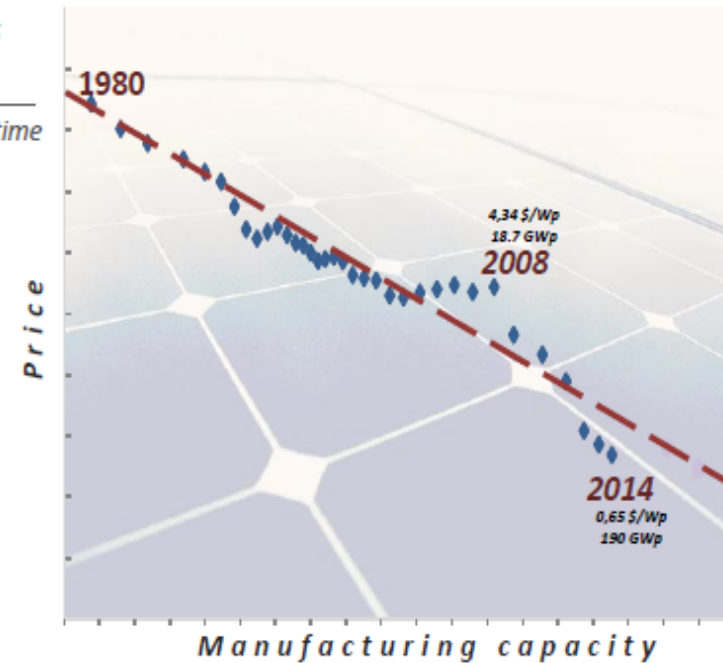
Drastic decrease of Costs for PV – A 2015 vision by Total

PV LONG TERM SCENARIO – A MASSIVE SCALE-UP

California LCOE* Cost



PV Module learning curve (20%)



Silicon modules > 90% global capacity
Module price divided by 5 since 2009



**LCOE is very dependant upon changes of the environment (prices of fuels, cost of new nuclear and production costs of solar energy in particular)
For wind energy and solar energy, cost of intermittency has to be added
LCOE is also very dependant upon the Discount rate.
(See Book 2 – Energy, Chapter 17)**



Levelized Cost of Electricity production (LCOE) = Discounted Costs/Discounted Production

$$LCOE = \sum_{k=0}^{k=n} \frac{C_k + O_k + F_k}{(1+i)^k} / \sum_{k=0}^{k=n} \frac{Q_k}{(1+i)^k}$$

- *Q : Production of Electricity*
- *C : Capital Expenditures*
- *O : Operating Expenses*
- *F : Fuel Expenses*
- *n : Economic Plant Life*
- *i : Discount Rate*
- *Due to discounting, decommissioning costs have a negligible effect (included in Capex)*
- *For Renewables, Intermittency Costs are not included*

Nota: In the following, raw data from IEA, US DOE, UK DBEIS, IRENA, Lazard, Fraunhofer ISE, WNA,.....



Solar Energy Installed Capacity Worldwide

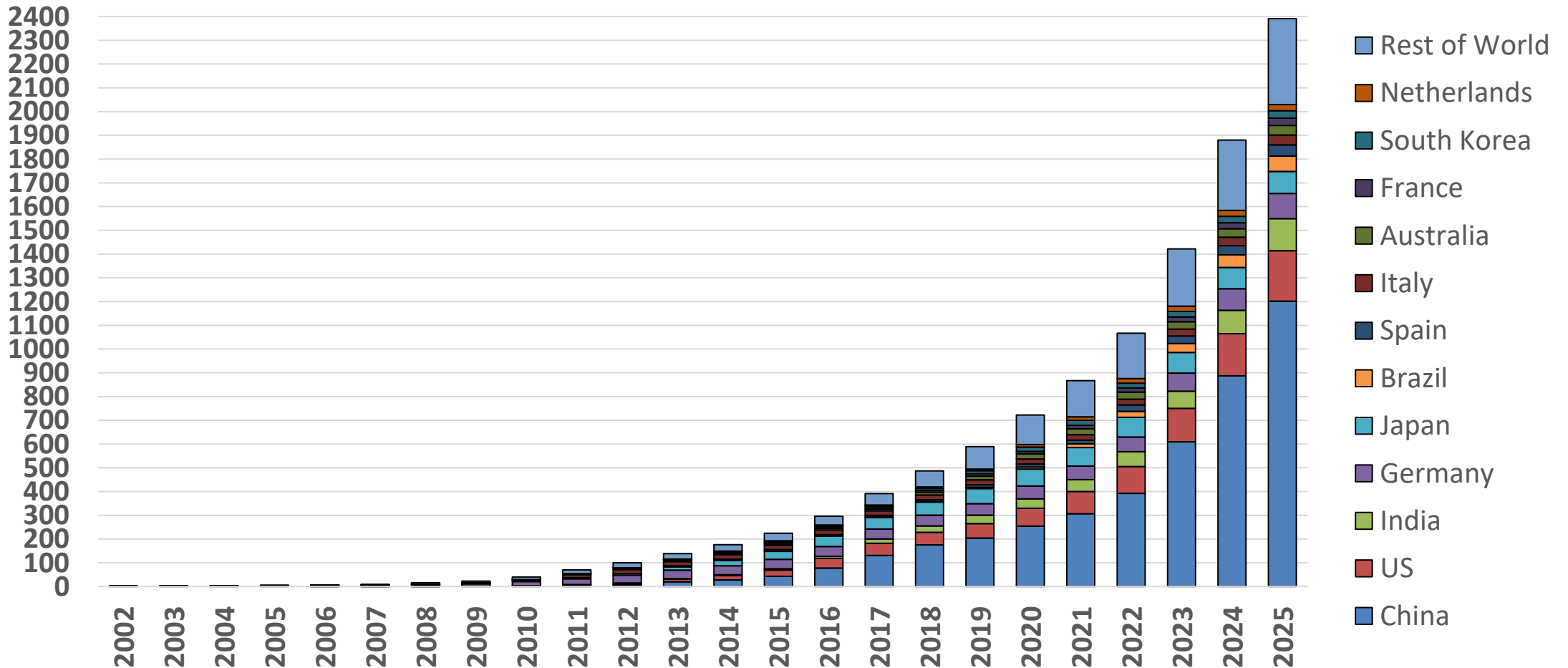
Figures may vary according to sources



Evolution of installed solar power capacity (MWp) N°1 China, N°2 US - End 2025

(GWp)

2400 GWp = +27% vs 2024 (CSP: 0,4%)

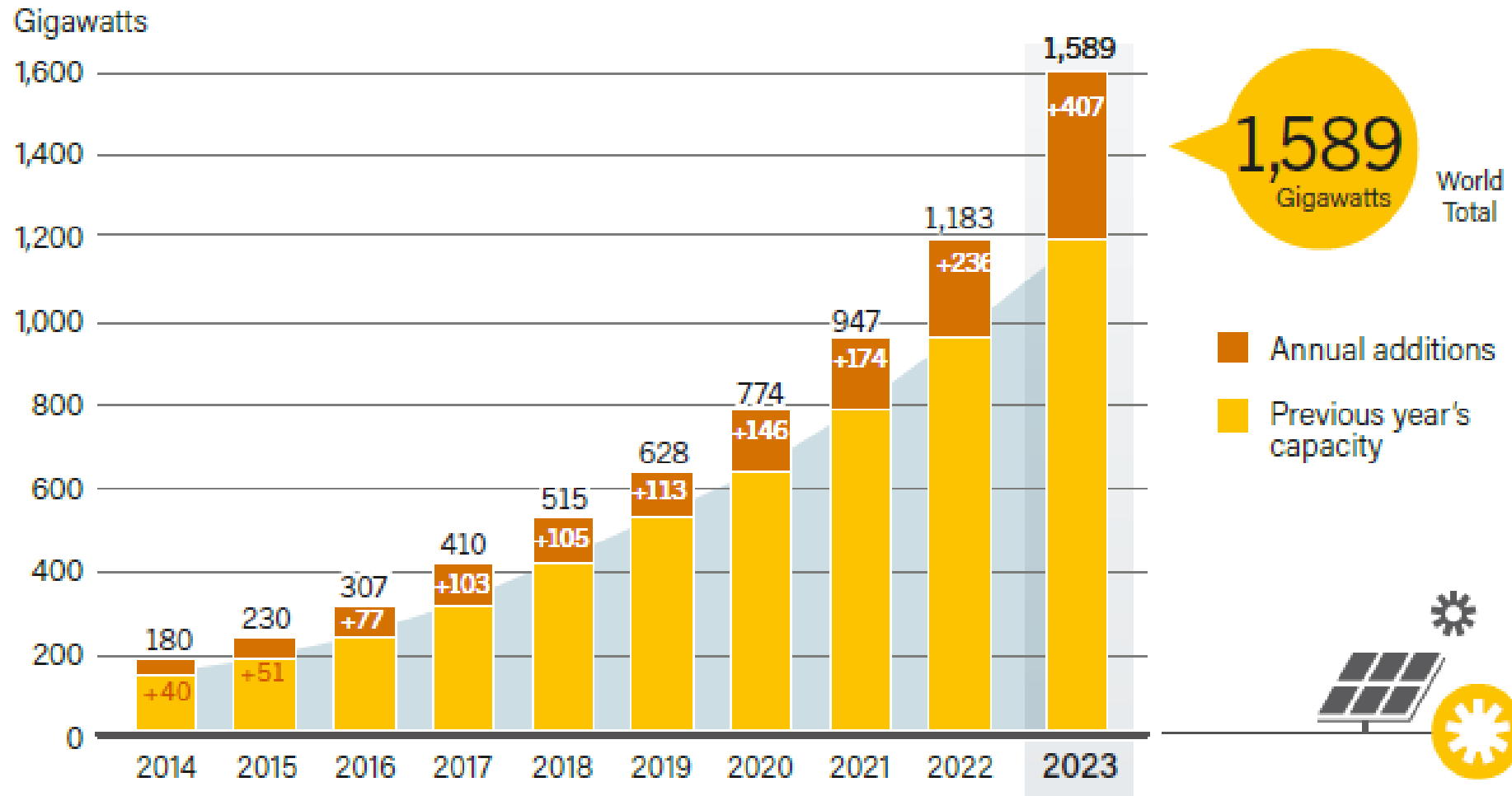


Source: Data from IRENA 2026

Figures represent the maximum net generating capacities installed and connected at the end of the year

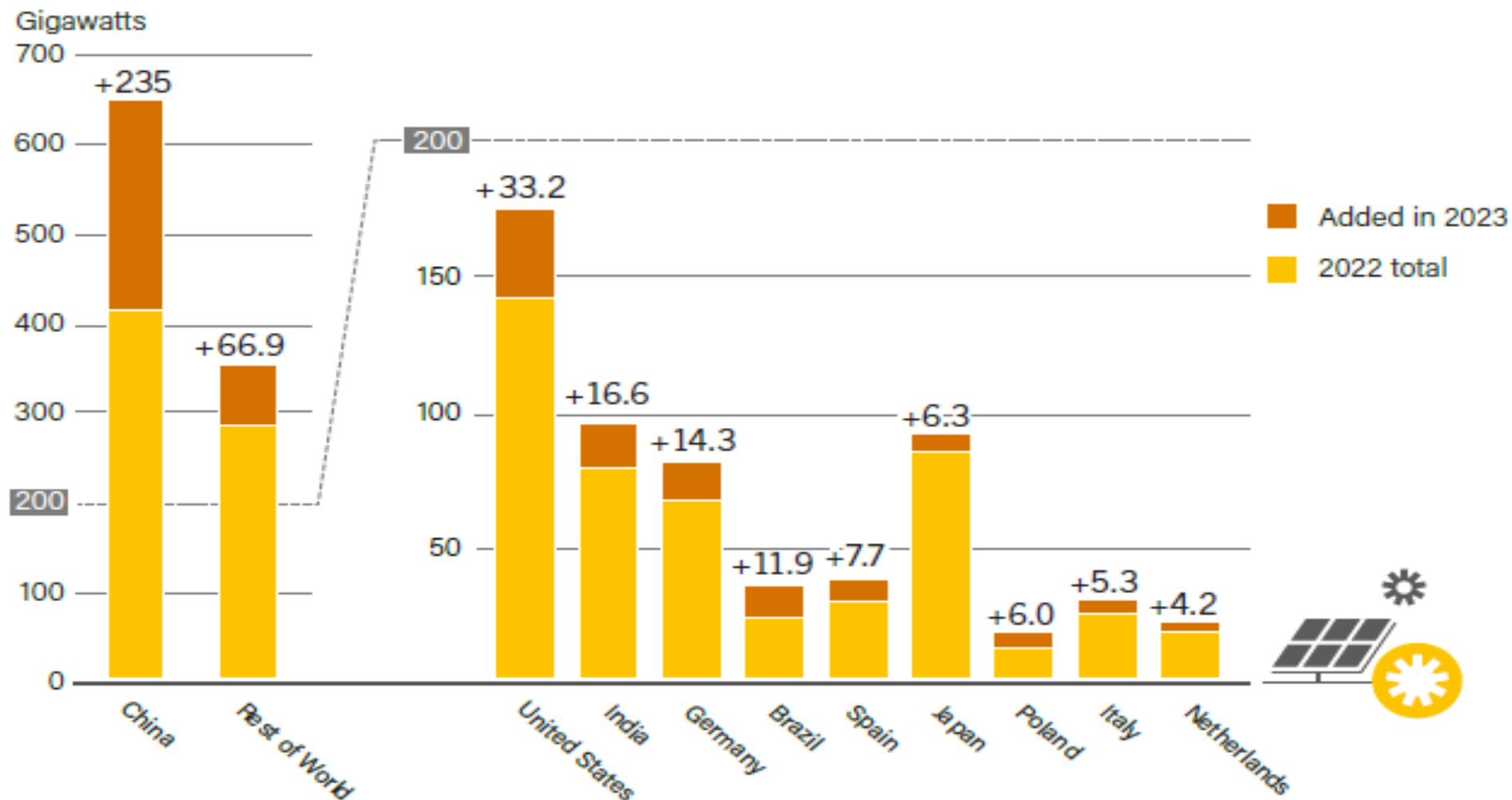


Solar PV Energy Installed Capacity Worldwide



Source: REN21 Renewables 2024 – Global Status Report

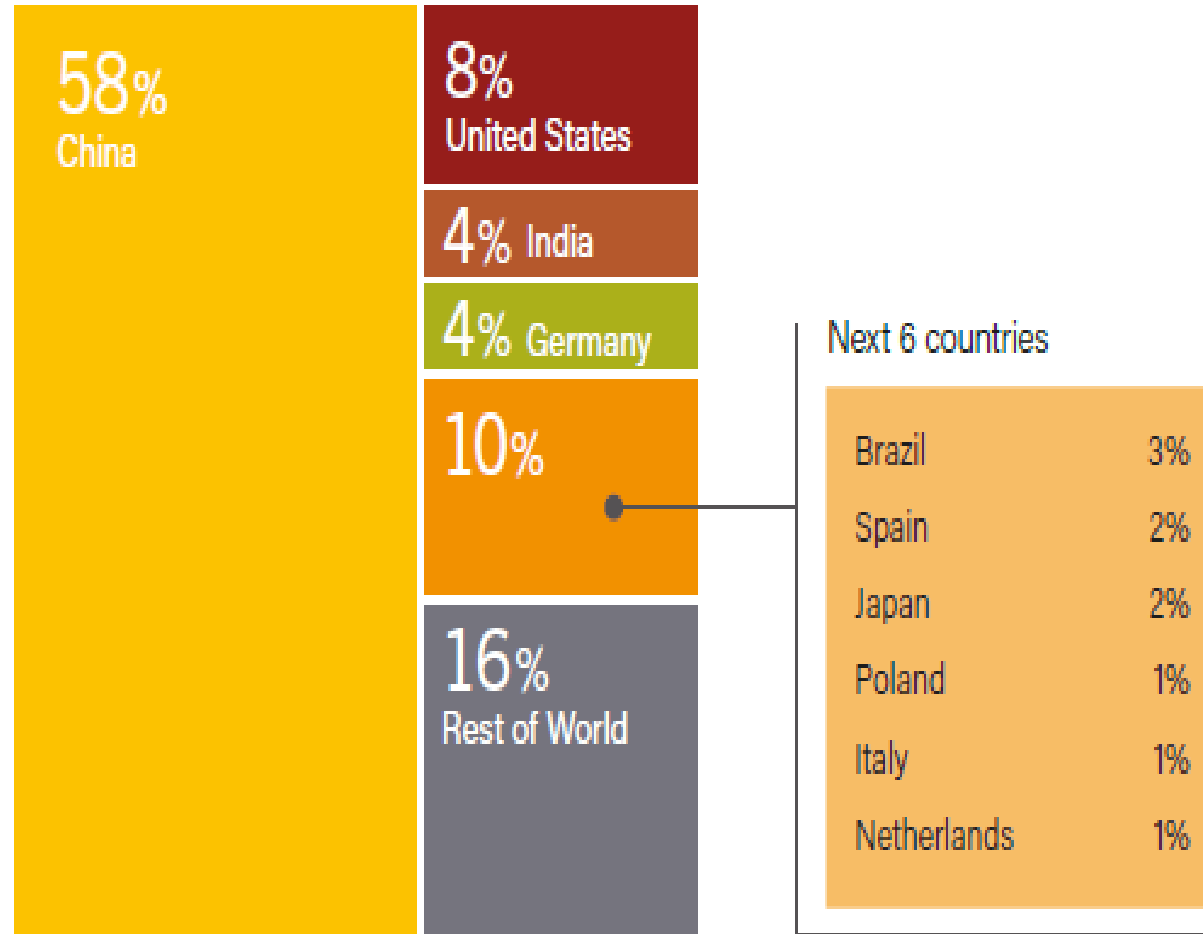
Evolution of installed solar PV power capacity (MWp) Capacities and Additions – Top 10 countries 2023



Source: REN21 Renewables 2024 – Global Status Report

Solar PV Capacity Additions – Year 2023

Solar PV Global Additions 2023: **407.3 GW**



Thermal Solar Power

THERMAL SOLAR POWER

Thermal solar energy systems have three components: flat collector panels to recover heat from sunlight, a fluid-circulation system to carry the heat to where it is to be used or stored, and a regulation device to maintain the fluid at a final temperature suited to the relevant application (heating for a swimming pool or building, or even high-temperature industrial applications).



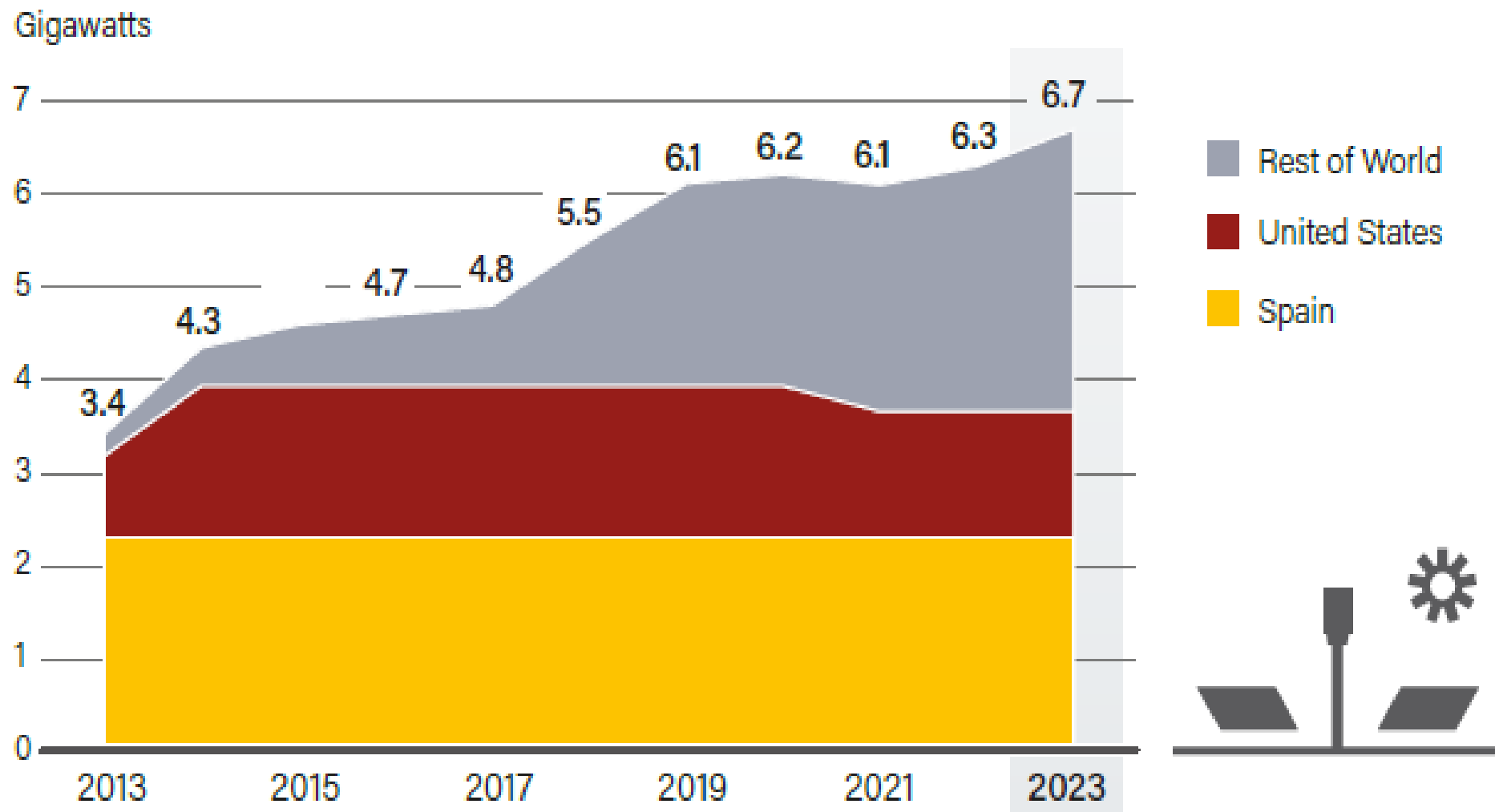
KEY FACTS

SOLAR THERMAL HEATING

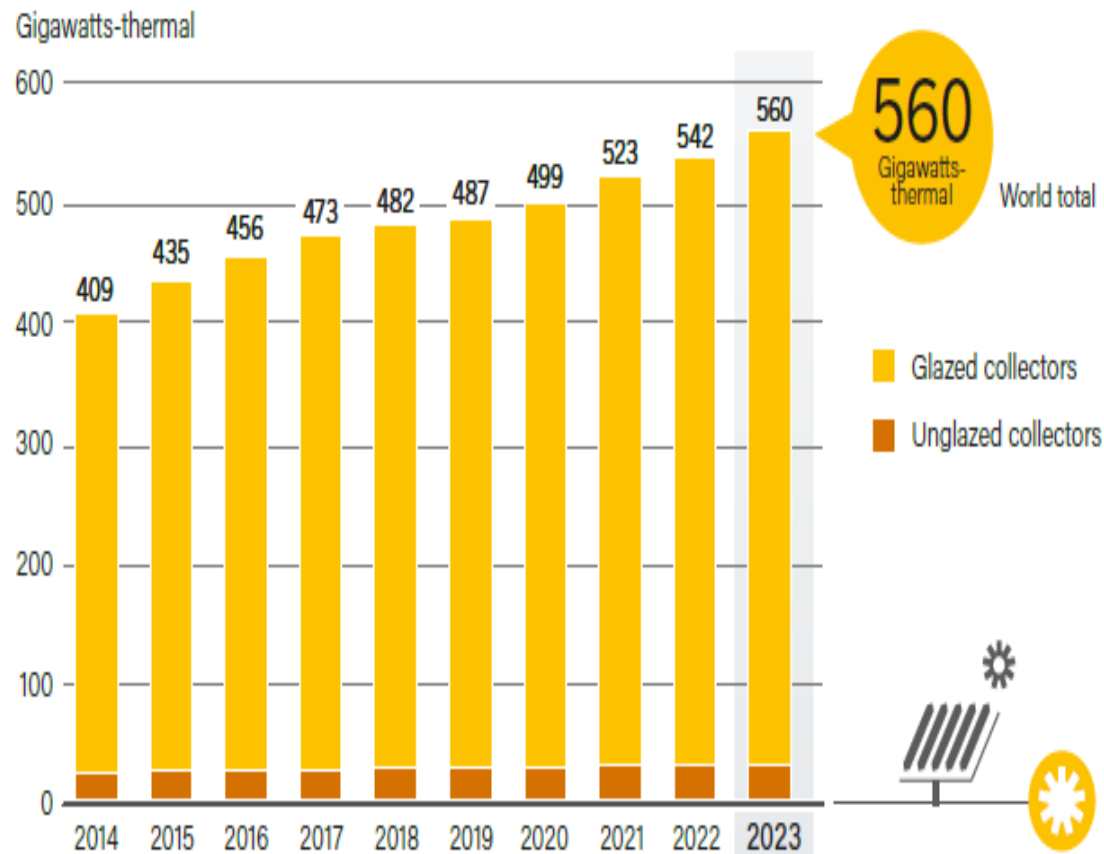
- The global market for solar thermal collectors contracted 7.2% in 2023, to reach a newly installed capacity of **21 GW_{th}**.
- Small-scale systems have lost market share in several regions, but demand for **large-scale projects** has risen in recent years.
- Globally, **337 large-scale solar thermal district heating systems**, with total capacity exceeding 1.9 GW_{th}, were operating by the end of 2023.
- In 2023, **116 solar industrial heat plants** (SHIP) began operation, bringing the global total to at least 1,209 installations supplying process heat.
- Solar thermal heating technologies continued to face market competition due to a **lack of awareness** and an imbalance in incentives.



Evolution of installed CSP thermal power capacity (GW)

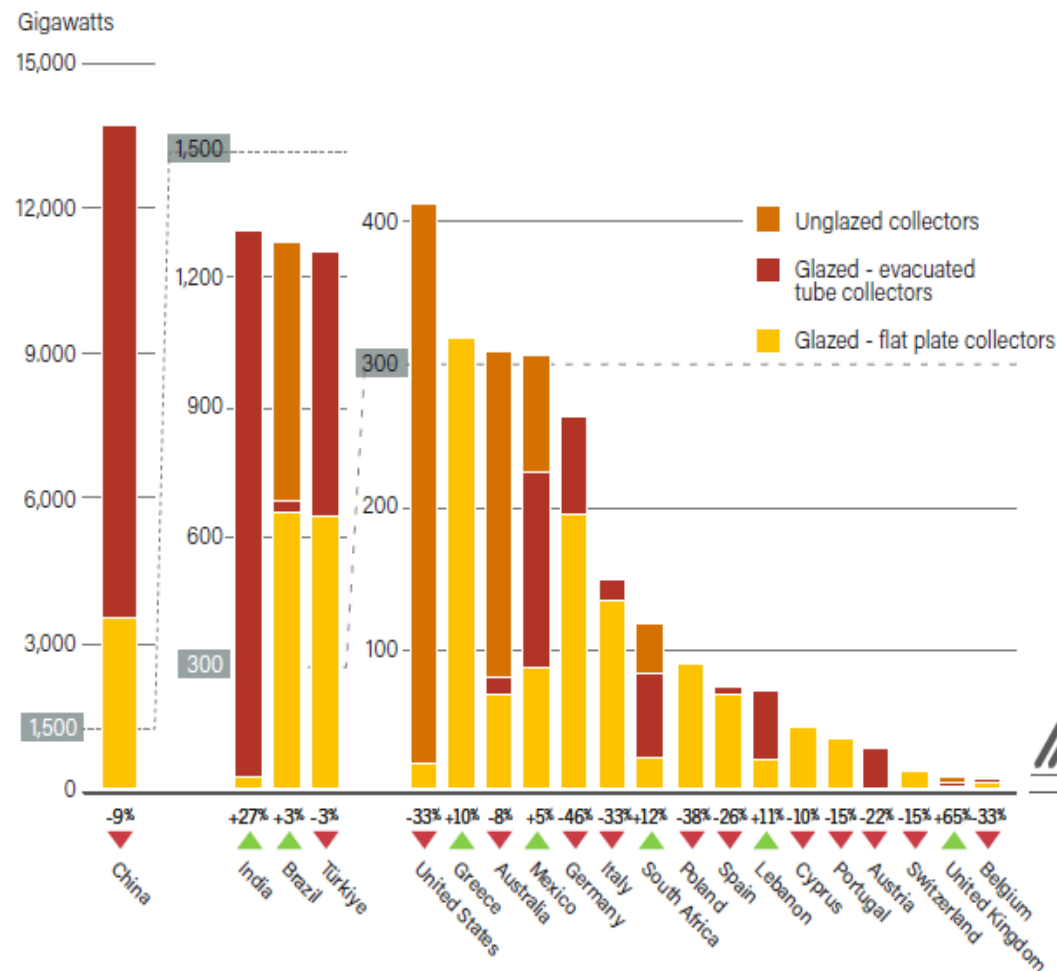


Evolution of installed Solar Water Heating Collectors Capacities



Note: Data are rounded to nearest GW_{th}. Data are for glazed and unglazed solar water collectors and do not include concentrating, air or hybrid collectors.

Source: REN21 2024

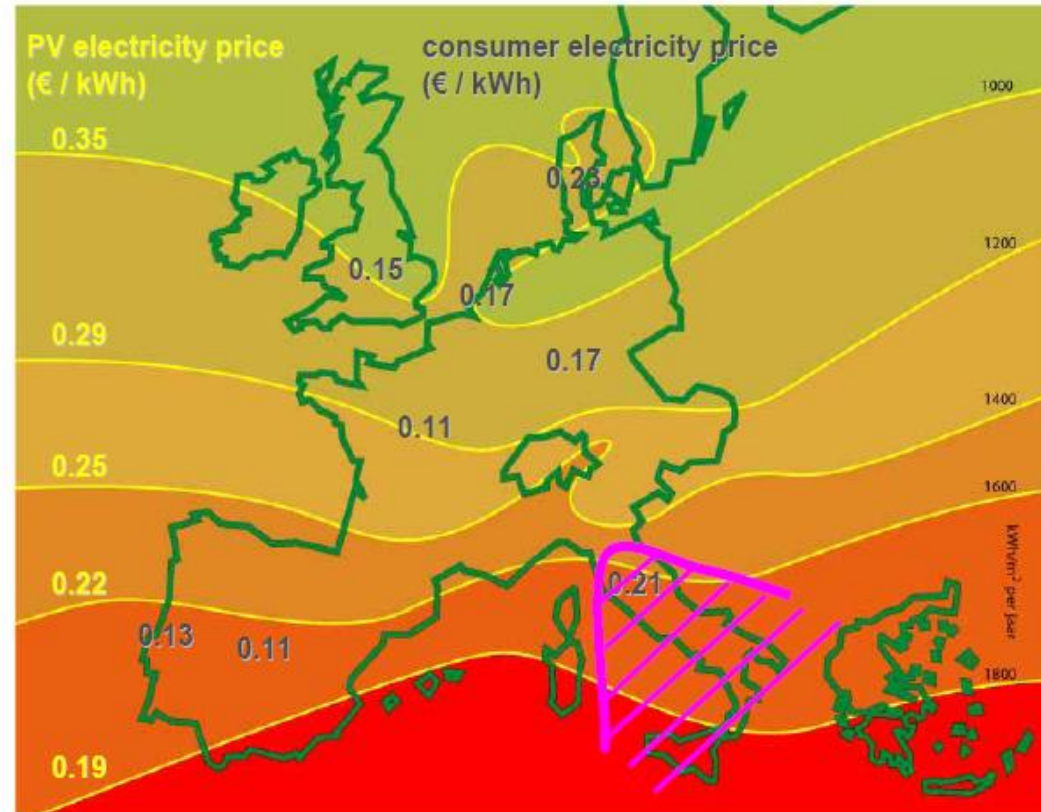


Note: Additions represent gross capacity added. Growth rates of annual market are rounded to the nearest whole number.



Solar PV electricity price vs consumer price

2010

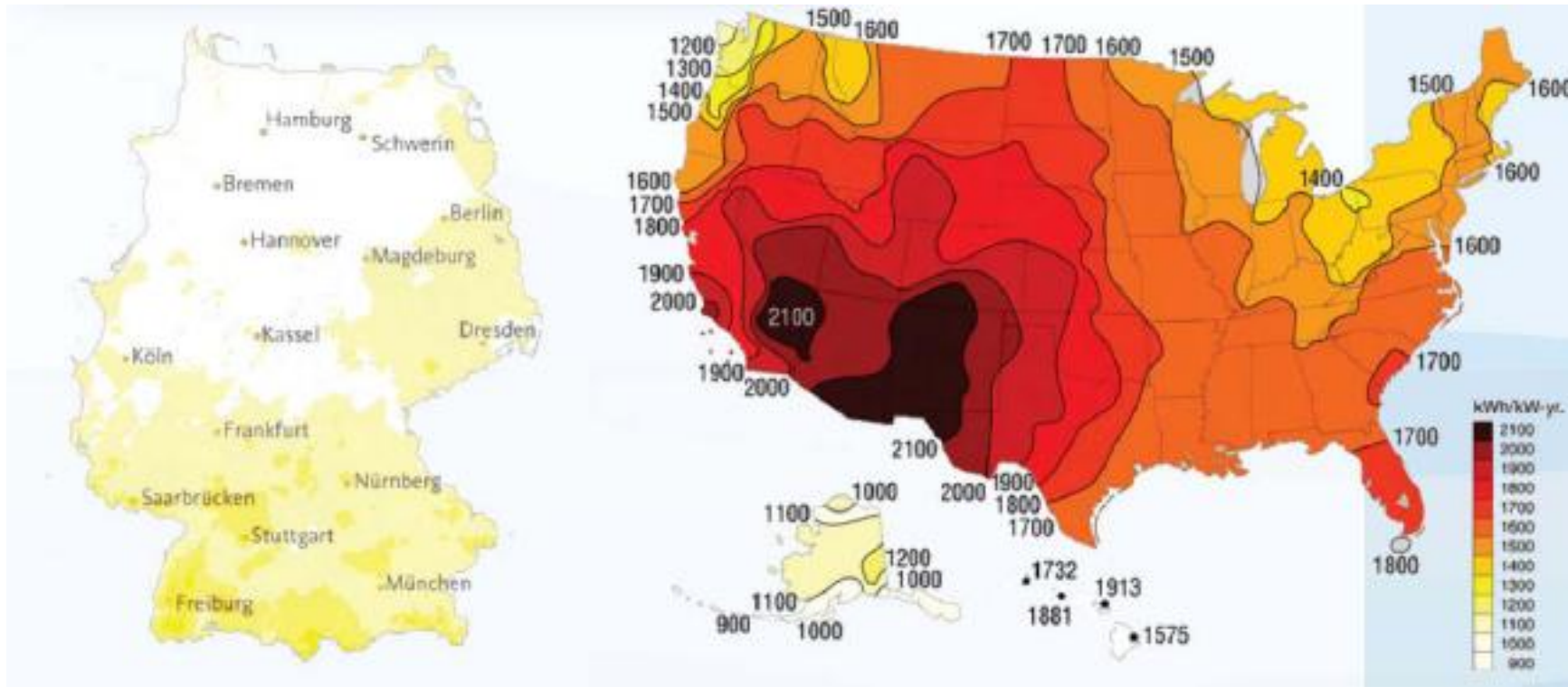


Source:
European Photovoltaic
Technology Platform

***The interest of this optimistic view is to illustrate the major roles of two factors:
Sun availability + intensity and alternative electricity costs or prices.***



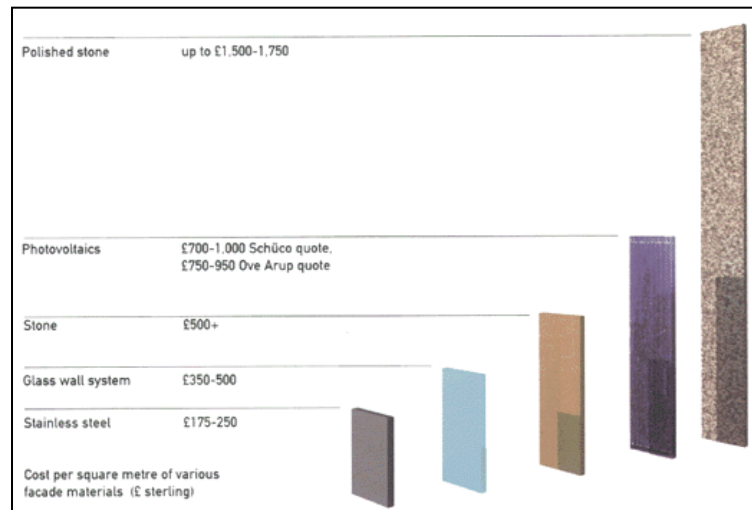
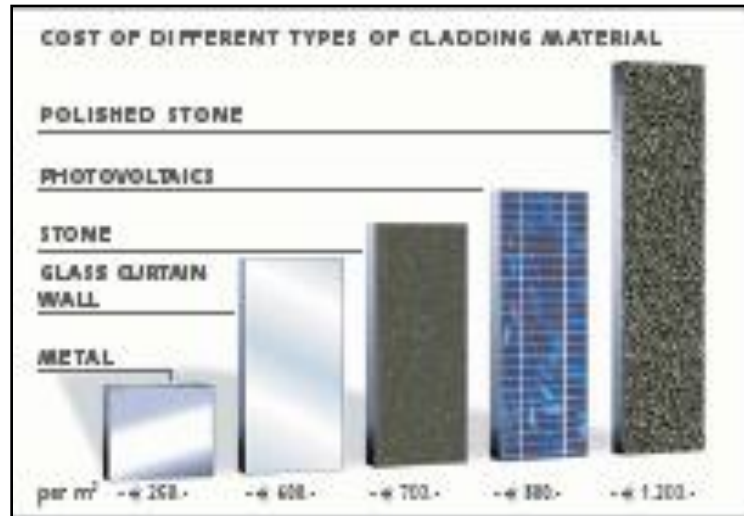
Solar resource: Germany vs US



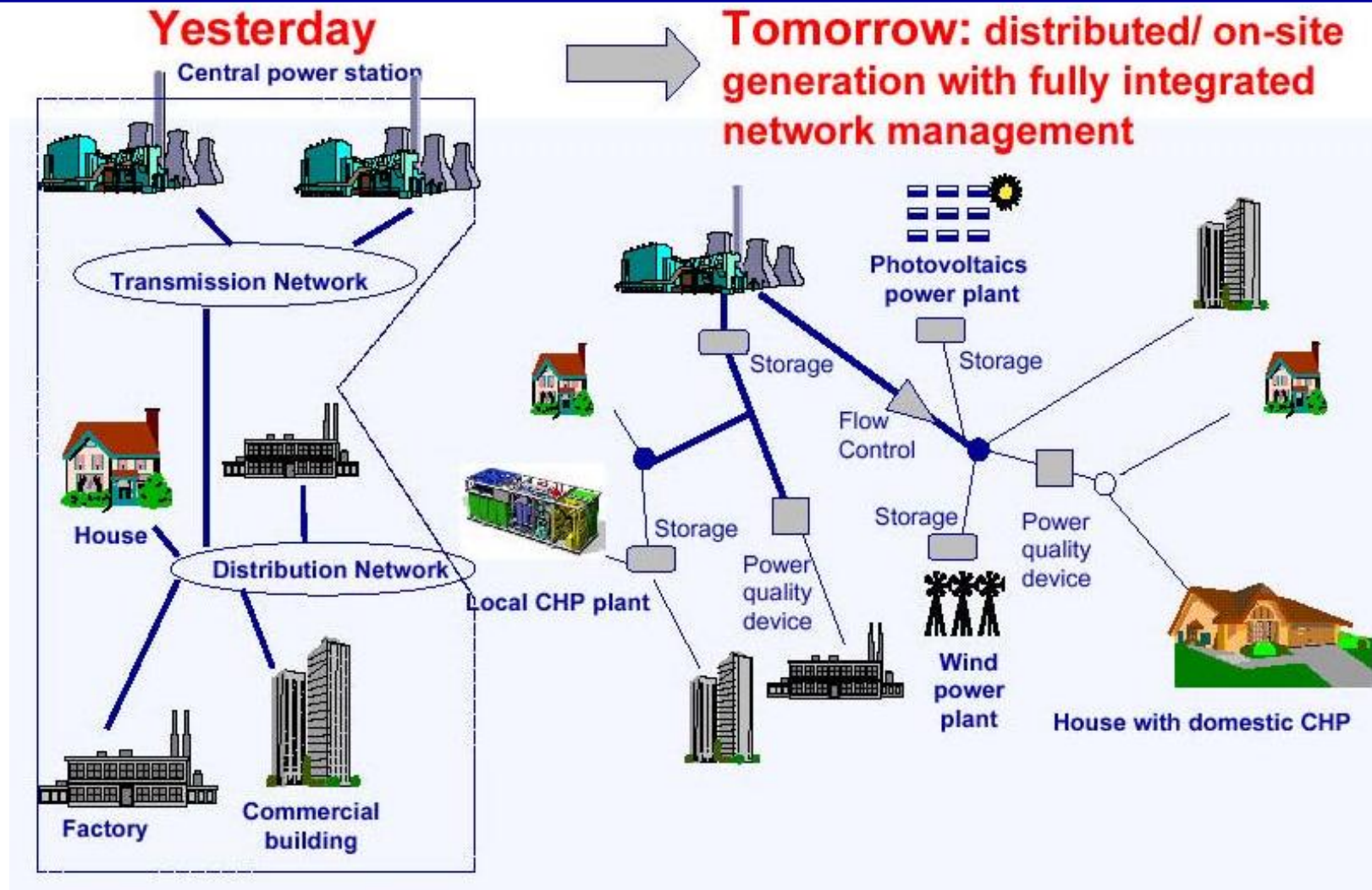
Nature is very « unequal » as far as solar energy is concerned ...



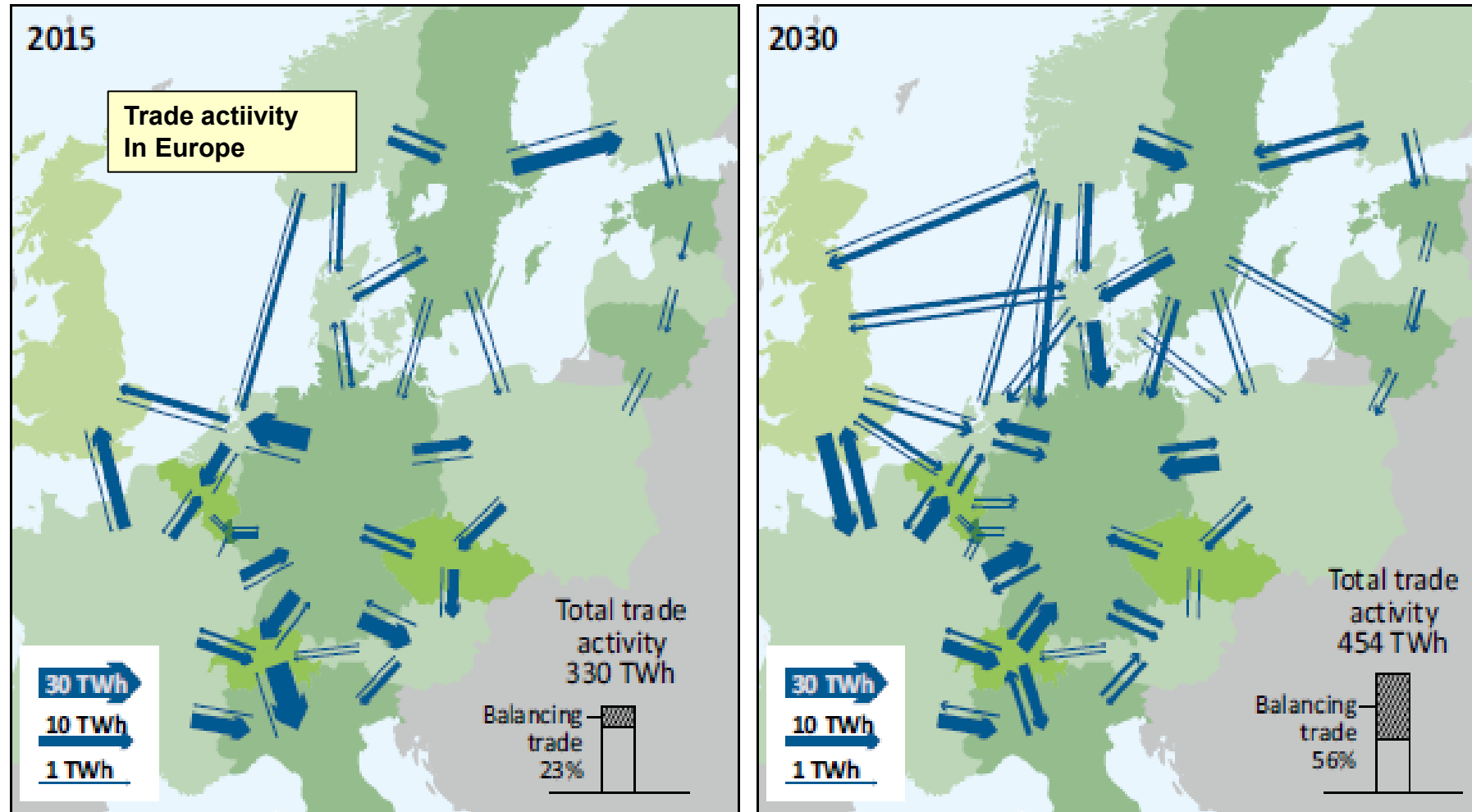
Can Solar PV electricity be for free ?



Breaking The Rules

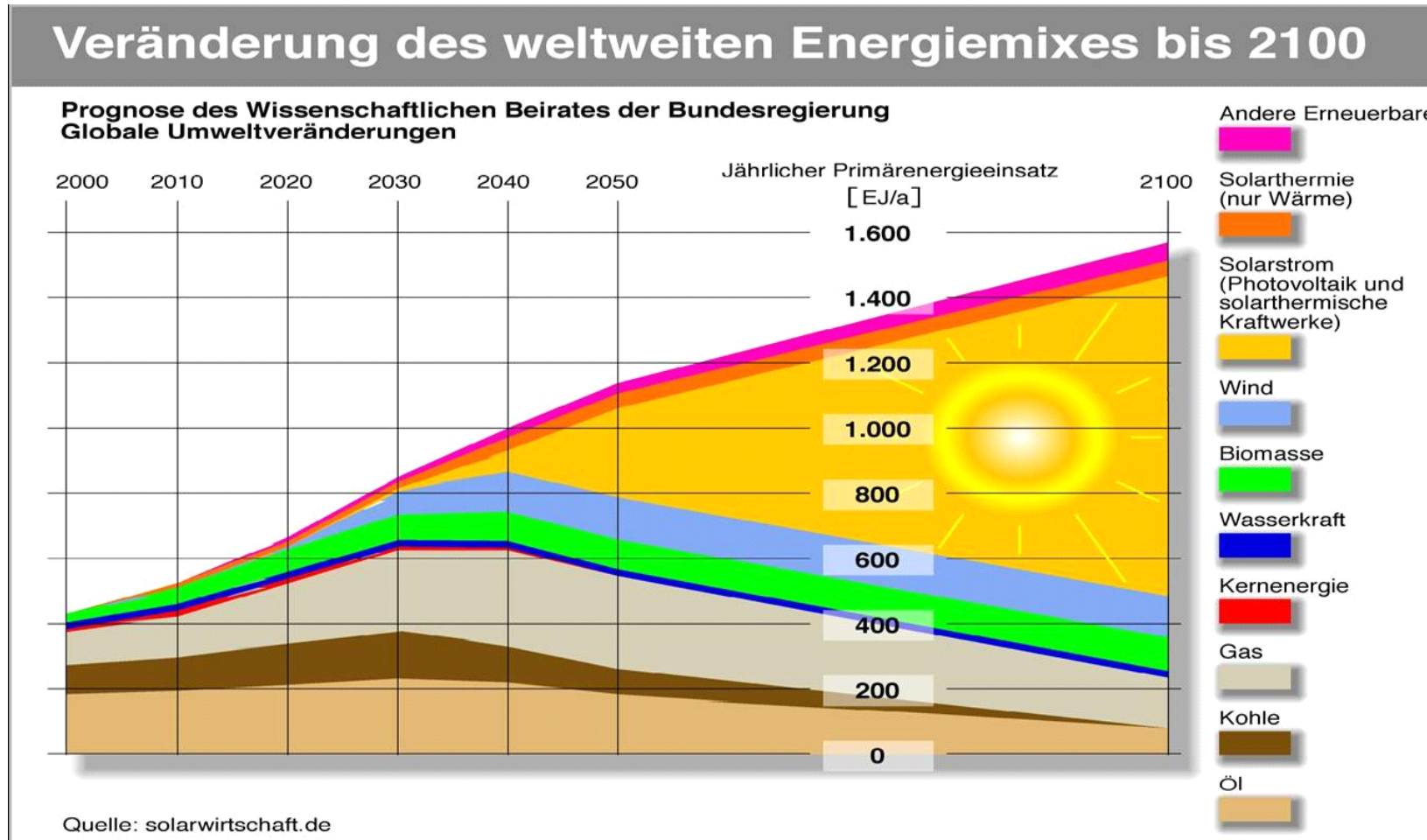


Integration is the Must to optimize the utilisation of Variable Renewable Energies



Solar Energy: a bright future ?

(A german view of Solar long term future)



This type of view assume a major breakthrough in solar energy costs reductions



International Solar Alliance

- **Established during the COP 21 in 2015.**
- **Enters into force on 6 december 2017.**
- **As of december 2017: 46 countries signed the framework agreement, 19 countries ratified it.**
- **Head Office: Delhi - India**
- **1000 B\$ to be captured to promote solar energy, in particular in developing countries.**

Easing Solar Deployment Globally

The International Solar Alliance is an action-oriented, member-driven, intergovernmental organisation for increased deployment of solar energy technologies as a means for bringing energy access, ensuring energy security, and driving energy transition in its Member Countries.



104

Member
Countries



16

Signatories
Countries



Biomass Energy





**Omuta Biomass Power Plant, Japan
supplied with Palm kernel shells**



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1. Global Remarks on Renewable Energy Sources

- Renewables in the Energy Mix –Trends/Perspectives – Investments – Potential/Diffusion/Network – Subsidies – Intermittency – Competitiveness – France PPE – Total Positioning – Criticality of Mineral Matters Resources – Dismantelment/End Life Equipment Recycling

2. Wind Energy

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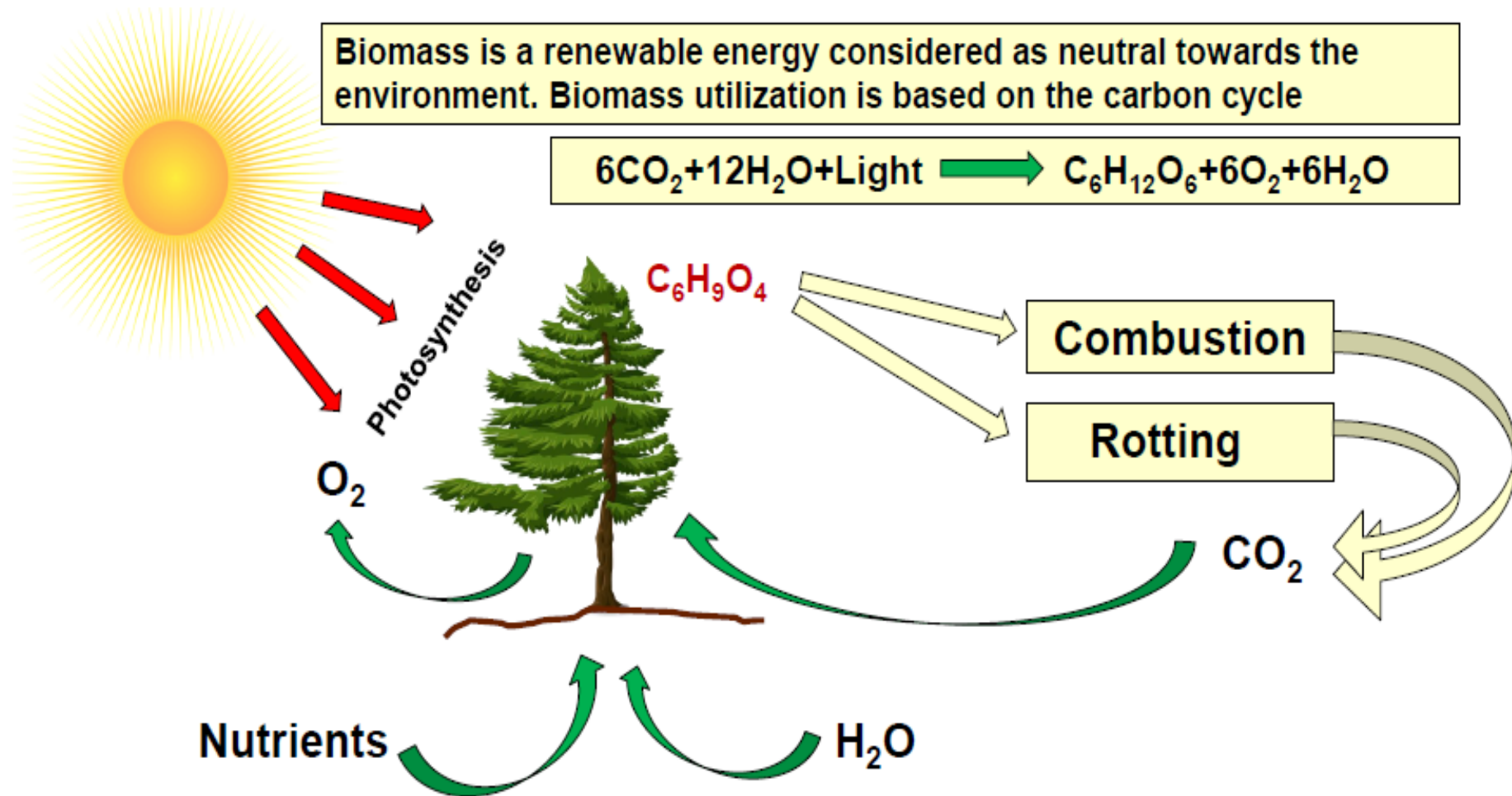
4. Biomass Energy

5. Geothermal Energy

6. Marine Energy

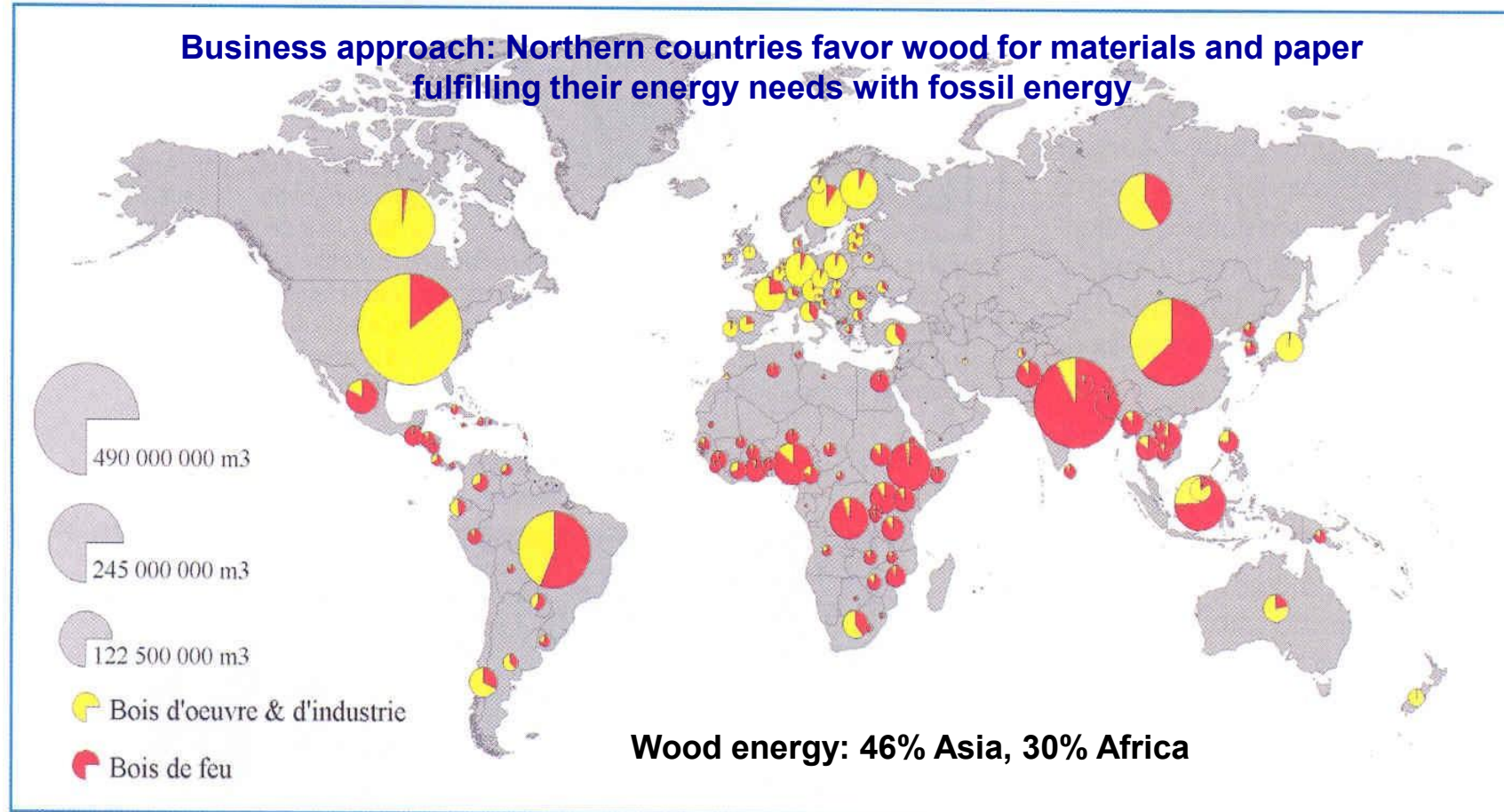


Biomass is neutral towards the environment



Nota: Wood is an organic material
Chemical formula # $\text{C}_6\text{H}_9\text{O}_4$

Wood energy is currently the most significant biomass contributor, esp. in developing countries (~900 Mtoe)



World wood consumptions (expressed in round wood equivalent)

... and can bring a lot to local heat and electricity markets

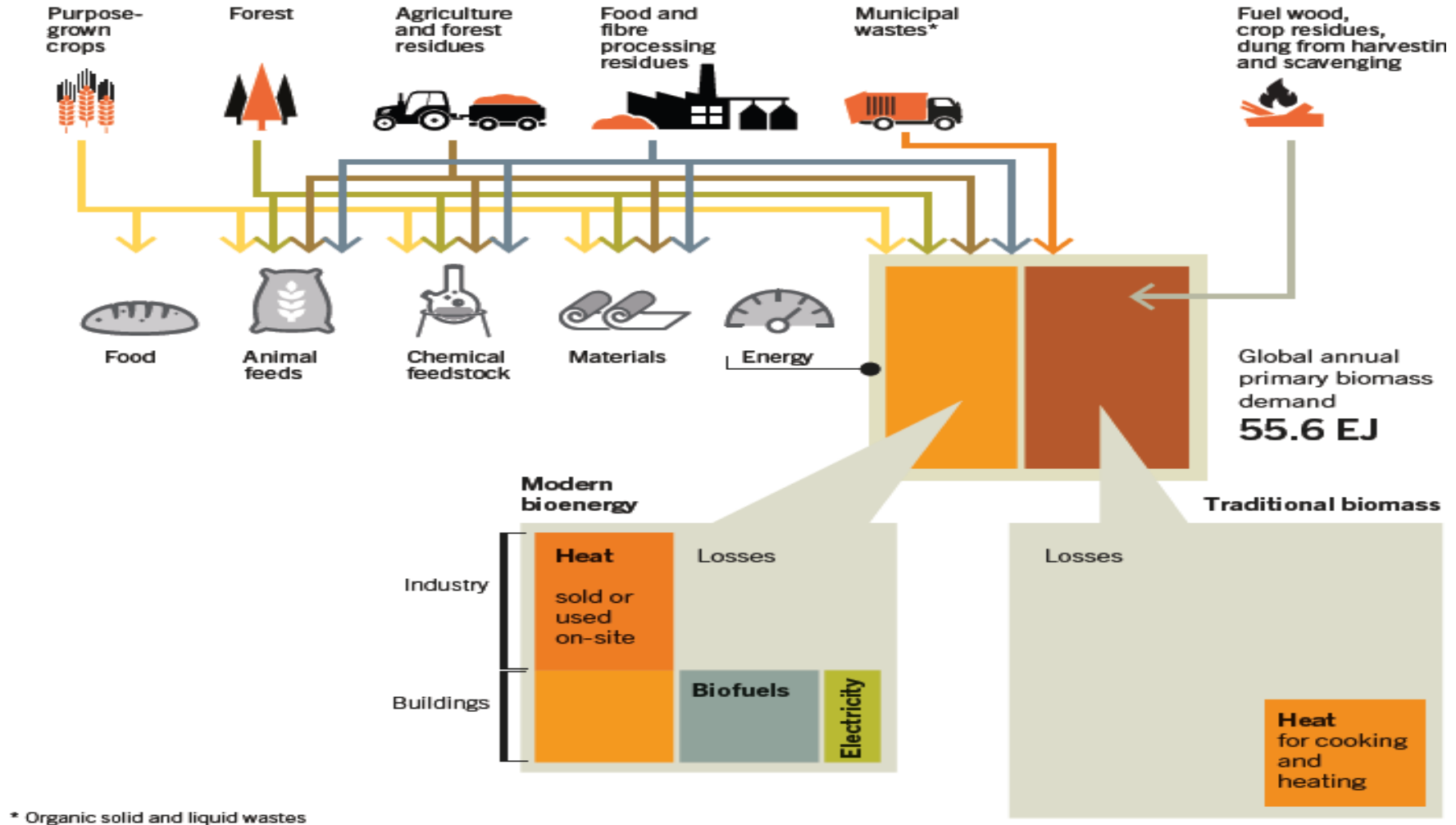


Biofuels: a lot of publicity, a number of problems, but still very small contribution to world energy (~35 Mtoe)

- ◆ **Biomass with an « obvious » potential and interest ...**
 - Brazil, USA, Europe ...
 - But as well China, South East Asia, Latin America, Africa ...
 - Local Heat and Electricity easier markets than biofuels ...
 - Due to difficult economics, public support is required in most of the cases ..
- ◆ **But attention will have to be paid to ...**
 - Land availability, and possible conflicts of use (food)
 - Water availability, and possible conflicts of use
 - Deforestation and biodiversity impacts, soil erosion
 - Life cycle analysis (greenhouse gases, fertilizers, pesticides ...)
 - Socio-economics (agriculture and agrobusiness issues)
- ◆ **A need for a better collaboration between science, agriculture, agrobusiness and energy companies**
 - “Competences blending” is very necessary

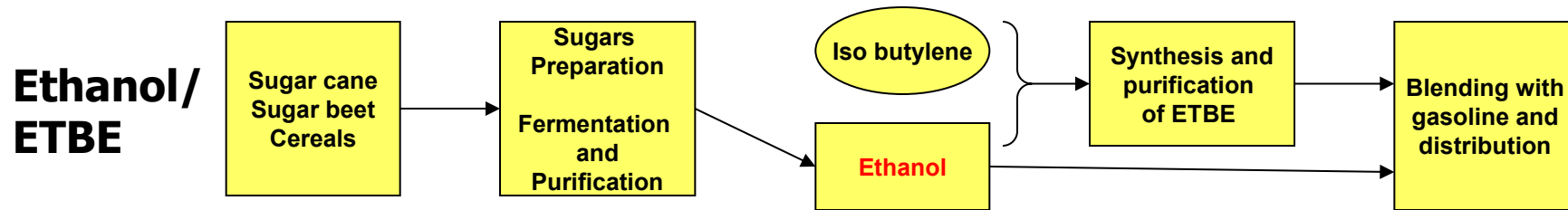


Biomass & Energy Pathways

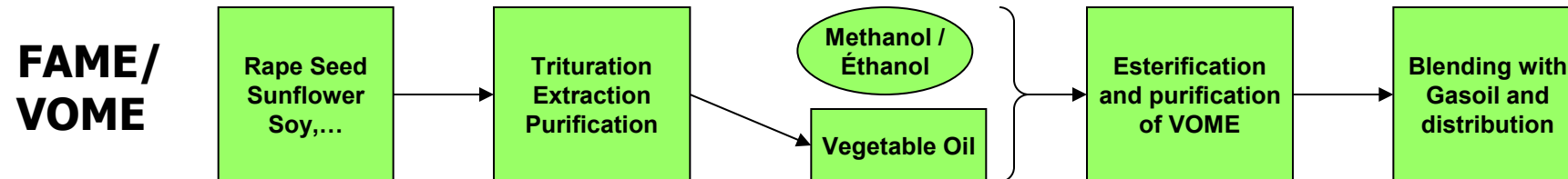


**But, as biomass is the only renewable source able to produce liquids,
biofuels are more and more looked after**

Ethanol and ETBE (Ethyl Tertio Butyl Ether) for gasoline



Vegetable oils for diesel (VOME: Vegetable Oil Methyl Ester/FAME: Fatty Acid Methyl Ester)



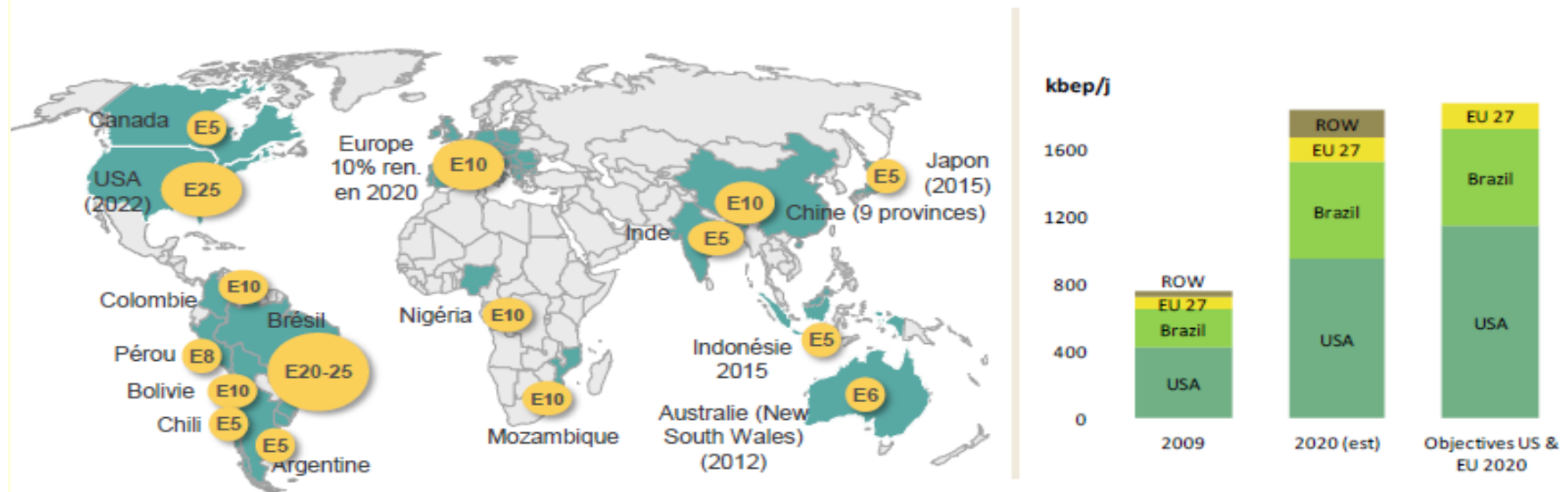
**Bioethanol + Biodiesel: so far a limited contribution (# 80 Mtoe 2017
World Consumption, mainly Brazil & USA) but a fast growing one**



Ethanol

Ethanol : cadre réglementaire et demande associée

Objectifs d'incorporation en éthanol et demande estimée

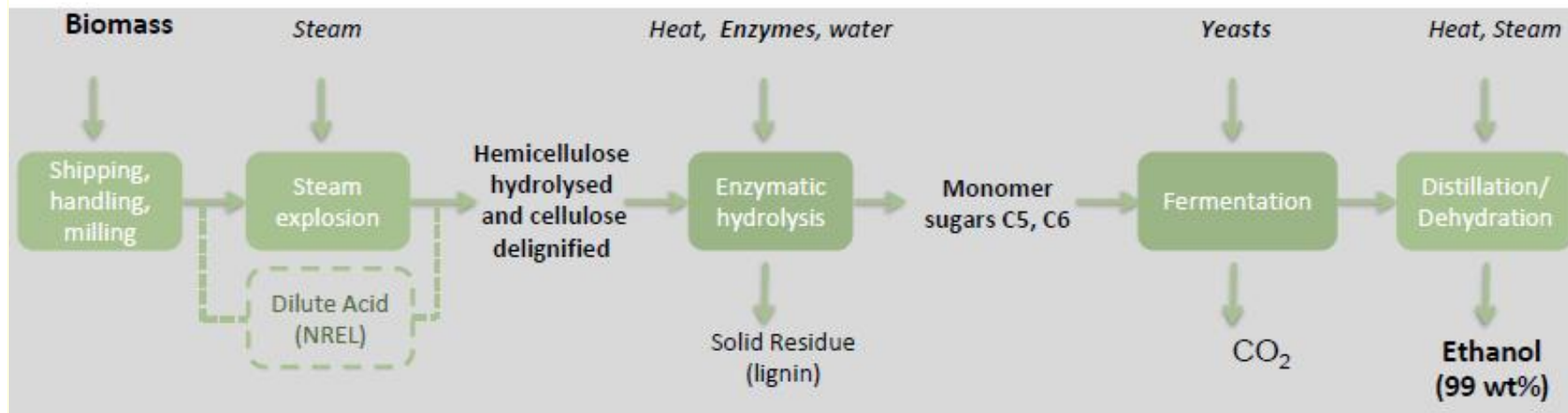


Note: Ex = x% d'incorporation éthanol. Source: IEA

- > USA et Brésil sont les principaux producteurs de bioéthanol
- > De nombreux pays d'Asie et d'Amérique Latine affichent des ambitions de développement des incorporations de biocarburants



Ethanol lignocellulosique



Milled biomass



Biomass after steam explosion



Hydrolyzate after enzymatic hydrolysis



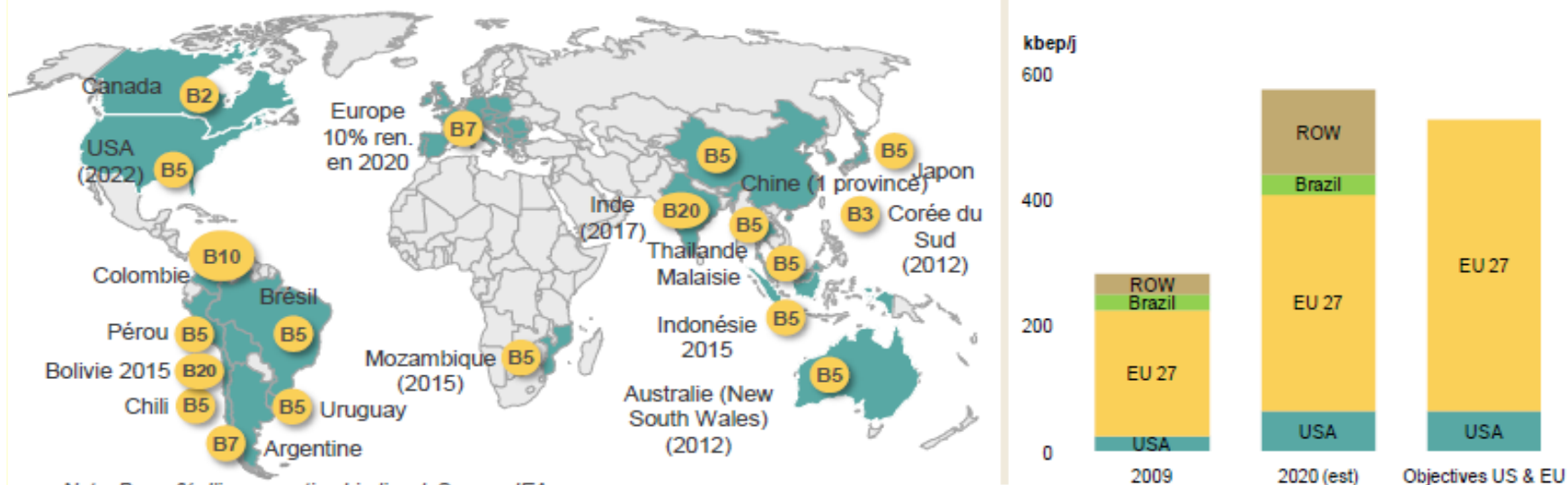
Ethanol



Biodiesel

Biodiesel : cadre réglementaire et demande associée

Objectifs d'incorporation en biodiesel et demande estimée



Note: Bx = x% d'incorporation biodiesel. Source: IEA

- > Développement du marché biodiesel dans les pays producteurs d'huile végétale et dans les pays émergents suite à une tension accrue sur les distillats
- > Soja et huile de palme : difficultés à passer les critères de durabilité édictés par les directives européennes



Biofuels: why so much conflicting noises ?



Fuel for food ... and food for fuel.

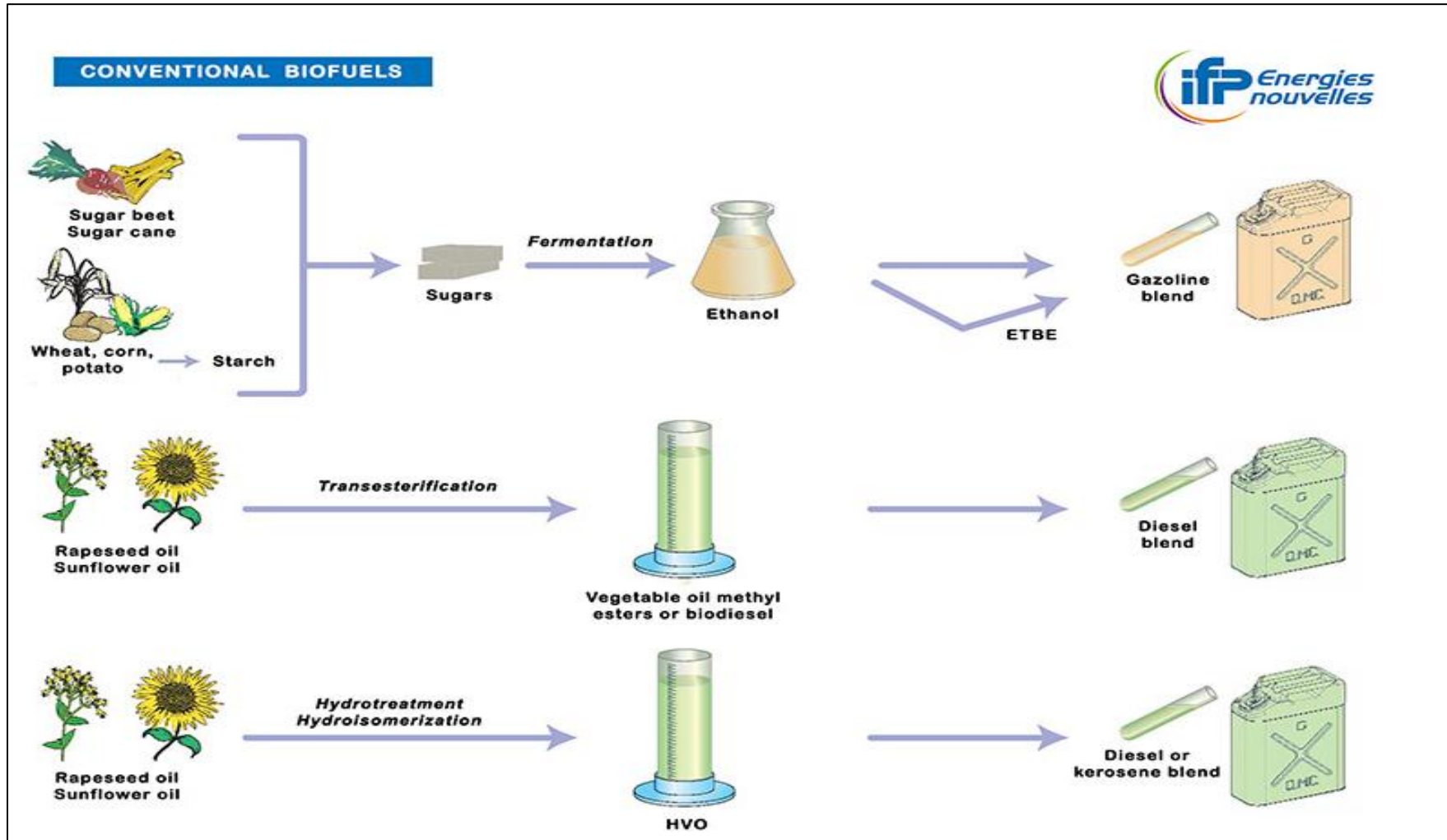


Never forget the energy and politics « linkages »



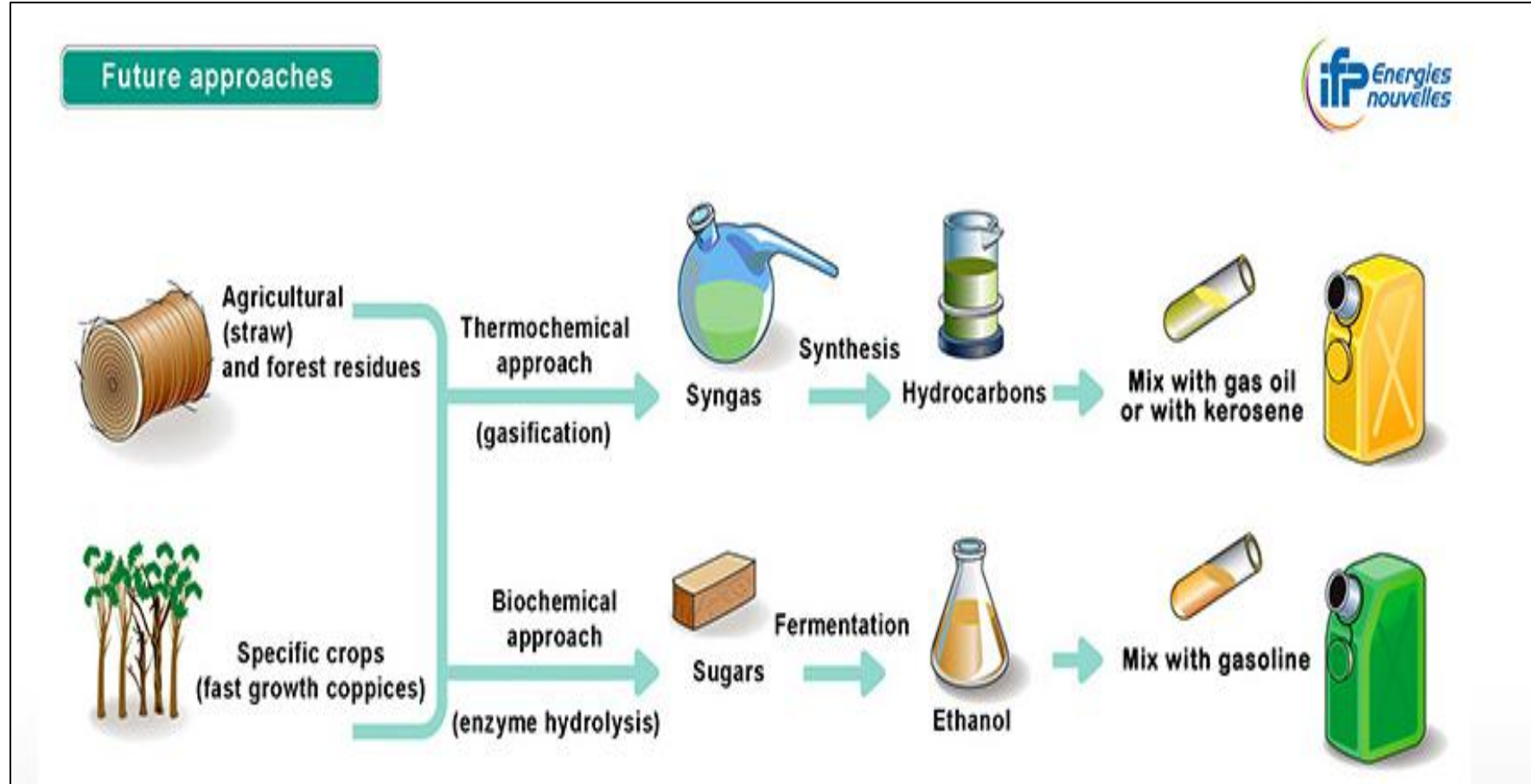
Due to resources limitations or conflicts with food markets, 2nd and 3rd generation biofuels are needed

Biofuels 1st Generation



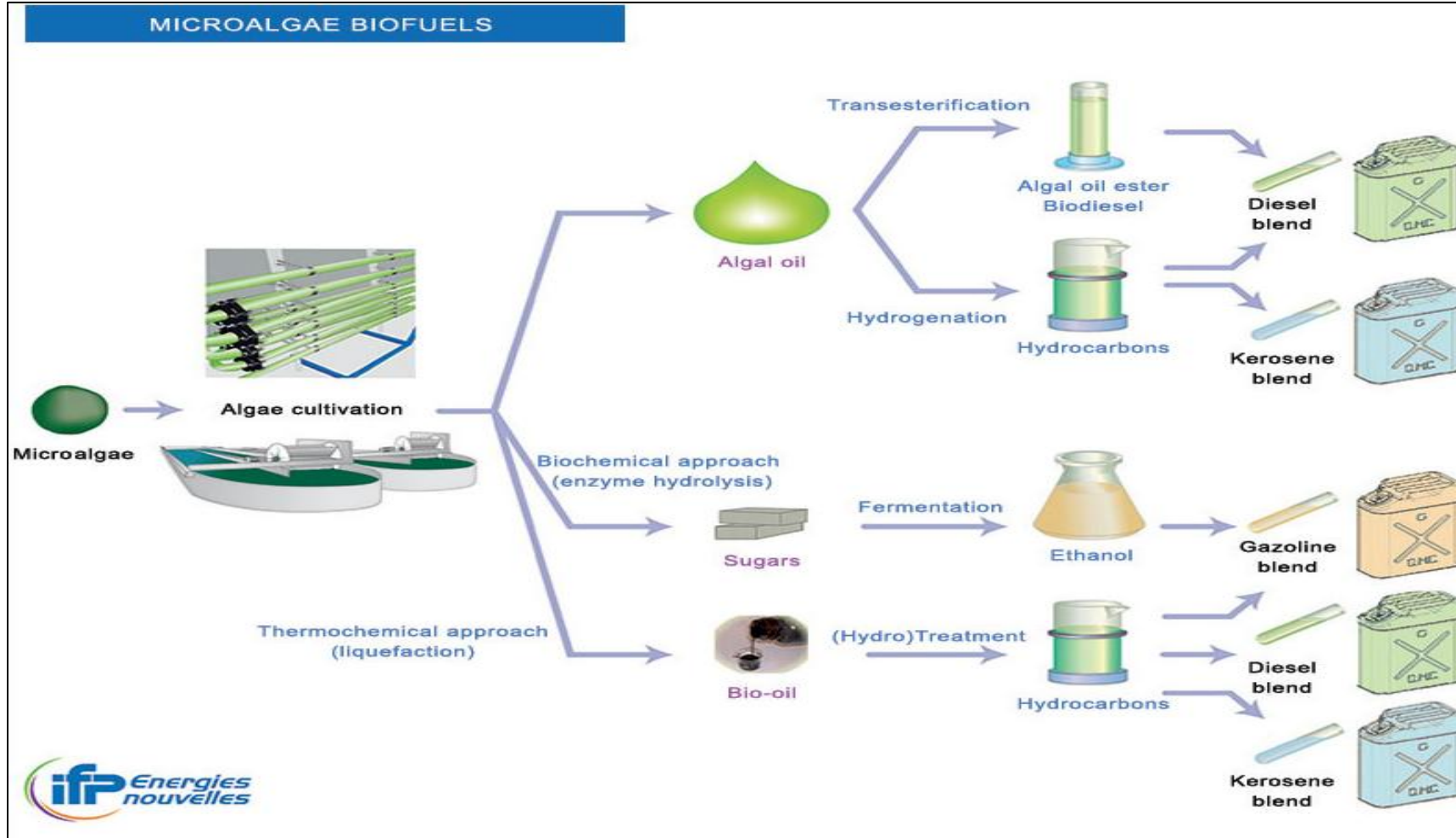
Due to resources limitations or conflicts with food markets, 2nd and 3rd generation biofuels are needed

Biofuels 2nd Generation



Due to resources limitations or conflicts with food markets, 2nd and 3rd generation biofuels are needed

Biofuels 3rd Generation



Agriculture: main types of Feedstock: 1st Generation 1G



Sugar Beet



Palm



Sugar Cane



Sunflower



Wheat



Corn



Soja



Main types of Feedstock: 2nd Generation 2G



Used cooking Oil



Animal fat



Manure



Grape marc



Animal by-product



Waste starch slurry



Waste/residues from processing vegetable oils



Main types of Feedstock: 2nd Generation 2G



Municipal waste



Forest residues



Wood processing waste



Agricultural residues

Waste/residues from processing
vegetable oils



Main types of Feedstock: Algae 3rd Generation 3G



◆ Advantages

- No land use and available marine surfaces
- High Lipid and Oil content

◆ Disadvantages

- Not mature yet
 - no scale plant
 - Contamination in open system
- Energy intensive



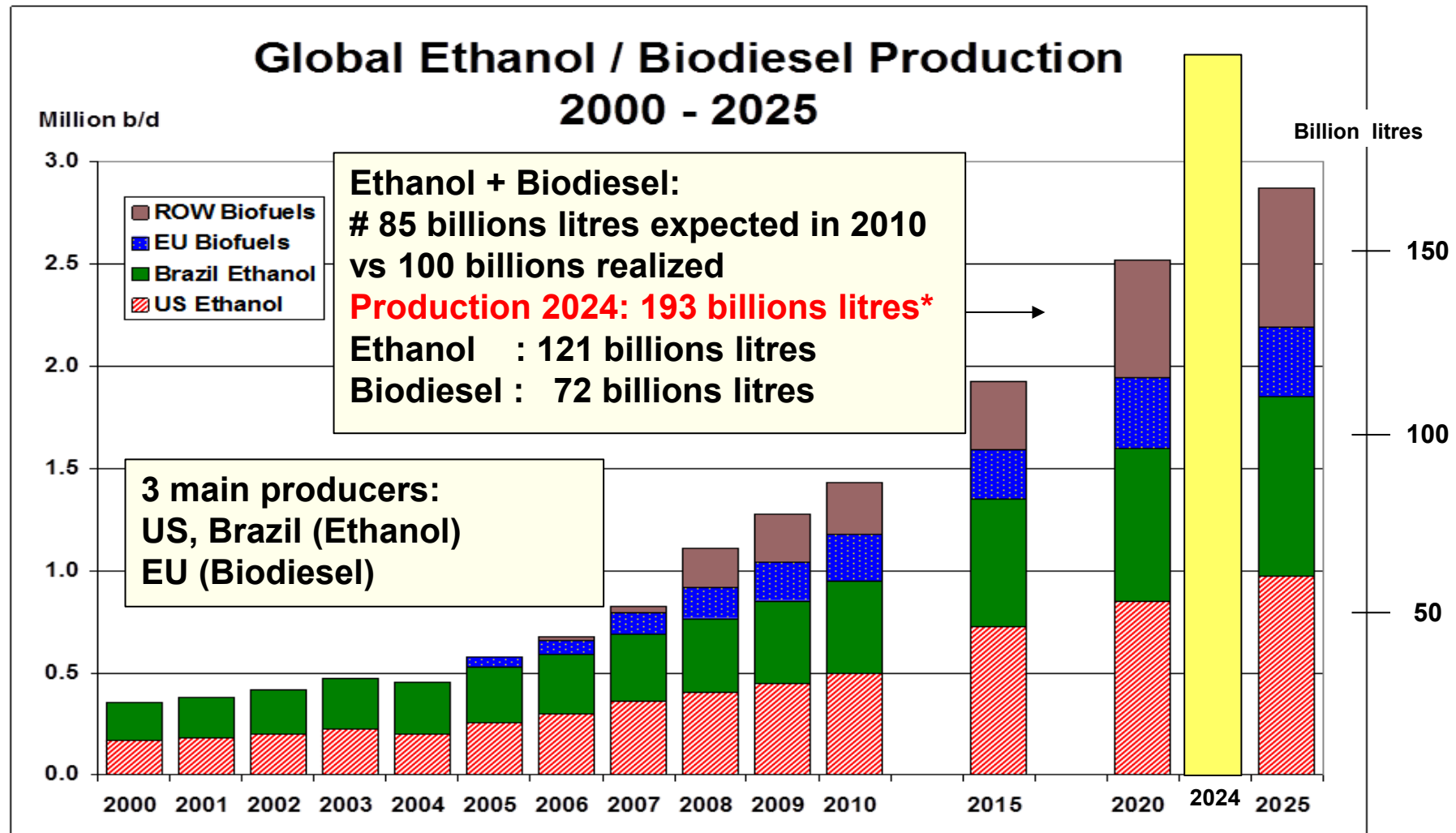
2nd Generation Biofuels Commercial Projects

- ◆ **Beta Renewables: Crescentino Italy, 80 Million liters/year**
- ◆ **Indian River County BioEnergy Center: Florida, 30 Million liters/Year**
- ◆ **Futurol: Project started in 2008. Production of ligno-cellulosic bio-ethanol. 11 Partners: Total/Tereos/Ademe France/Axens/Bpifrance, Commercial target: 2016. Pilot plant of 70t/d, Bucy, France. Capex = 76 M€.**
- ◆ **Project Liberty: Emmetsburg State of Iowa USA 75/100 Million liters/year, 250 000 T biomass treated by BioTechnology. Partners: POET-DSM Advanced Biofuels (USA-NL). Capex: 275 M\$. Financing: DOE (100 M\$), State of Iowa (20 M\$), USDA (3 M\$)**



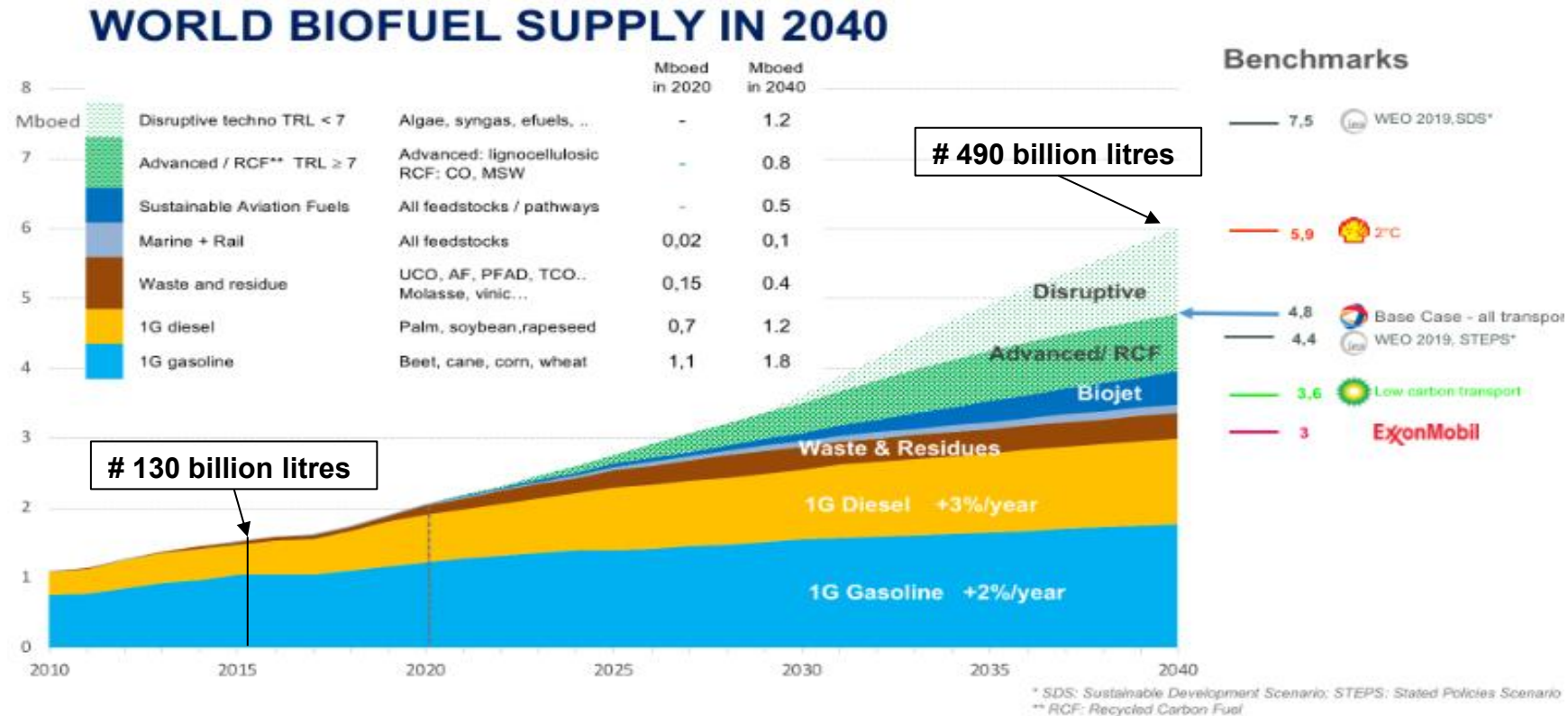
Biofuels Production Perspectives. A 2006 vision – A Growth well anticipated

Impact of Covid-19 in 2020



Biofuels Long Term Perspectives

TotalEnergies Scenario



- **Base Case Road from 2 Mboed (2020) to 4.2 Mboed (2040) corresponding to 10% of road fuel demand**
 - Demand increase mostly covered by 1G biofuels growth in Asia and America
 - Still need for 0.8 Mboed of advanced technologies
- **Base Case Jet: 0.5 Moebd by 2040 corresponding to 5% of jet demand**



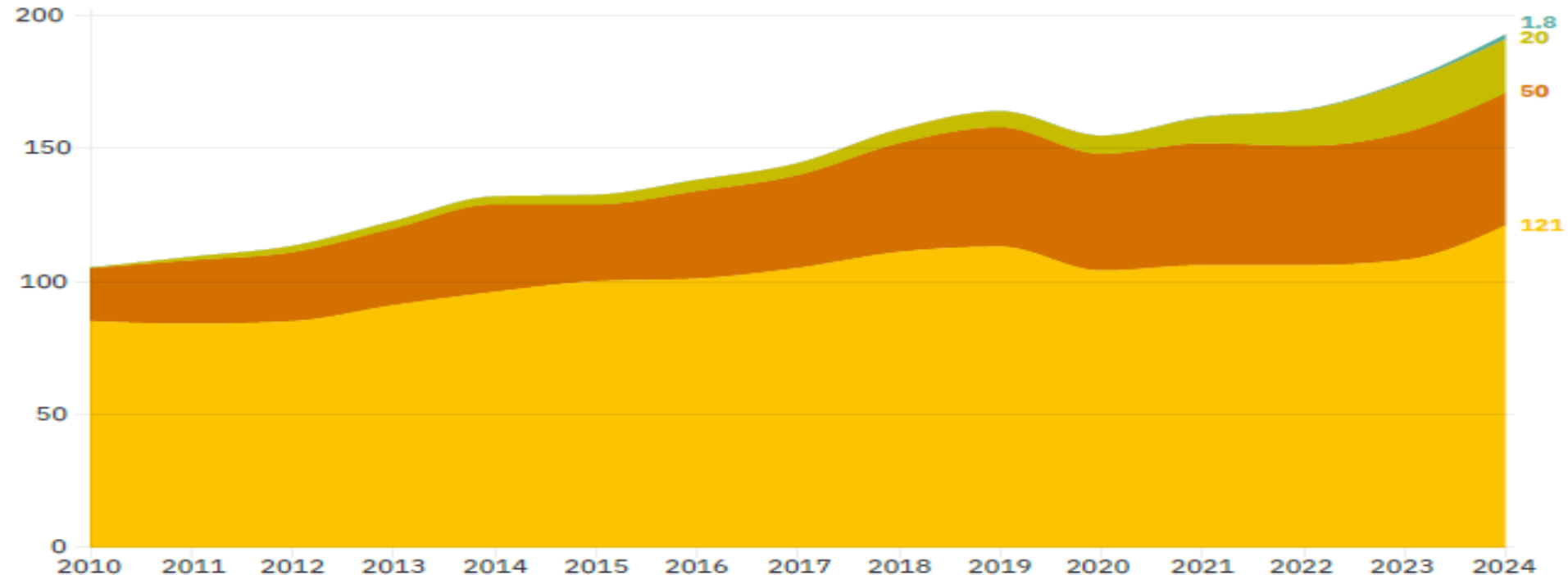
Ethanol & Biodiesel Production

Global Production of Liquid Biofuels, by Fuel Type, 2010-2024

Global liquid biofuel production reached nearly 193 billion litres in 2024, with renewable diesel and biojet fuel recording the fastest growth rates

● Bioethanol ● Biodiesel (FAME) ● Renewable diesel ● Biojet fuel

Billion litres



Source: World Bioenergy Association, 2025⁴⁰

REN21

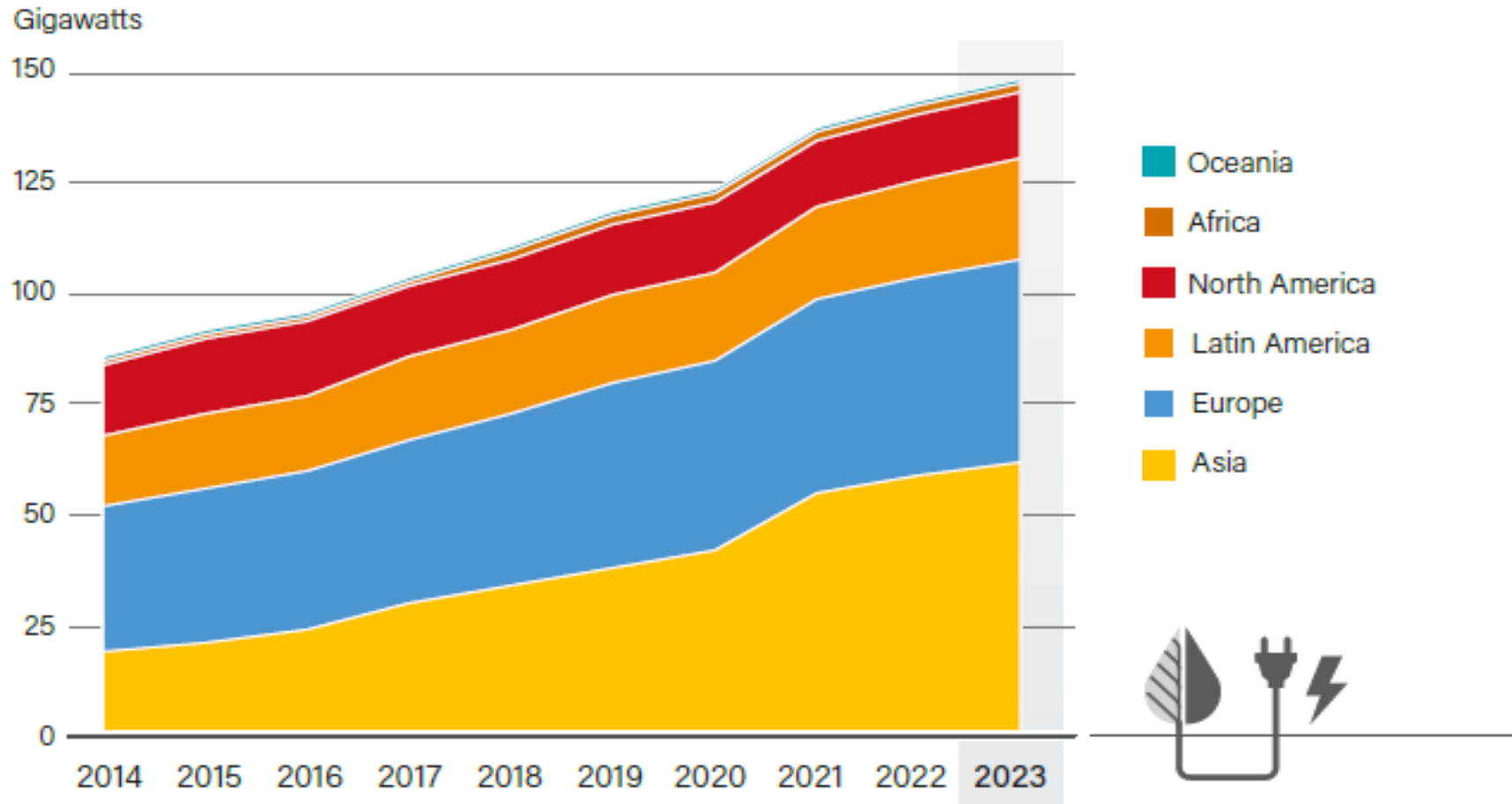
HVO

Note: HVO = hydrotreated vegetable oil; HEFA = hydrotreated esters and fatty acids; FAME = fatty acid methyl esters



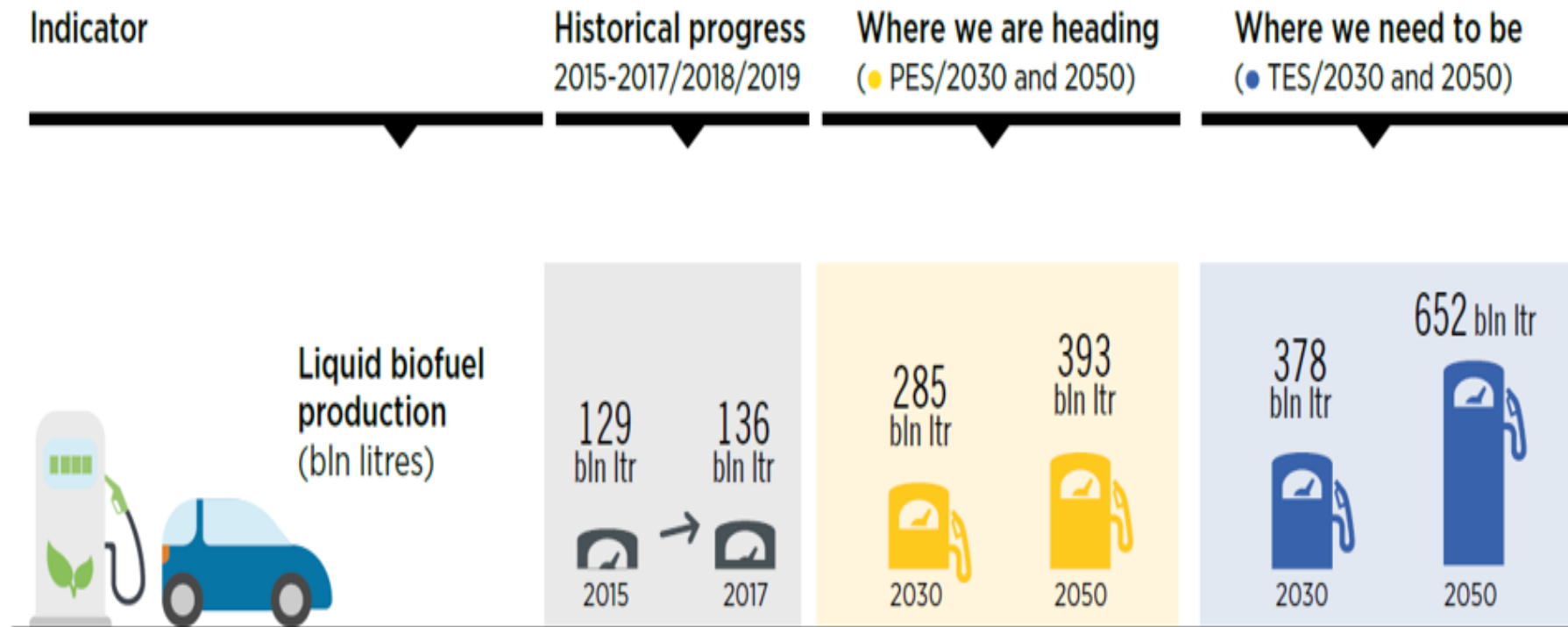
Bioelectricity Capacity by Regions 2014 - 2023

A regular Growth



Biofuels Long Term Perspectives

Vision IRENA 2020 Scenarios



PES : Planned Energy Scenario = Primary reference case

TES : Transforming Energy Scenarion = Keep rise in global temperature to well below 2°C and towards 1.5 °C during this century (COP 21)

Source: IRENA 2020



Sustainable Aviation Fuels (SAF) Qualification Process

ASTM D7566 Annex	Abbreviation	Conversion process	Possible feedstocks	Blending ratio (volume)	ATSM Qualification
1	FT-SPK	Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene (syngas to kerosene)	Coal, natural gas, biomass	50%	Sep-2009
2	HEFA-SPK	Synthesized paraffinic kerosene produced from hydroprocessed esters and fatty acids (lipids from plant and animal sources)	Vegetable oils and fats, animal fat (tallow), recycled oils (UCO), algae	50%	Jun-2011
3	HFS-SIP	Synthesized paraffinic kerosene produced from hydroprocessed fermented sugars	Biomass used for sugar production	10%	Jul-2014
4	FT-SPK/A	Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources (syngas to kerosene and aromatics)	Coal, natural gas, biomass	50%	Nov-2015
5 / 6	ATJ-SPK	Alcohol-to-jet synthetic paraffinic kerosene (through dehydration of the alcohol to an olefinic gas, followed by oligomerization to obtain liquid olefins of a longer chain length, hydrogenation and fractionation)	Biomass used for starch and sugar production, cellulosic biomass for isobutanol production, ethanol. Category can be expanded to include any C2-C5 feedstock	30% isobutanol 50% ethanol	Apr-2016 for isobutanol Apr-2018 Ethanol



A Zoom on Biofuels Development Scenario in the Framework of European Union Targets



EU: The Key Drivers - 3x20% by 2020

European Council March 2007, integrated in the law in 2009

+ 20% by 2020
EFFICIENCY

By 2020 - 20% GHG vs 1990

By 2020 20% RENEWABLES
(France: 23%)

BIO-FUELS

10 % 2020
binding

E-ELECTRICITY

HEATING & COOLING

NATIONAL TARGETS and ACTION PLANS



EU: The Key Drivers - 32%x40%x32% by 2030

New objectives of European Council 2018, for the period 2021-2030

**+ 32,5% by 2030
EFFICIENCY**

By 2030 - 40% GHG vs 1990

By 2030 32% RENEWABLES

BIO-FUELS

- 1st Generation Biofuels frozen at their 2020 level and < 7%
- Palm Oil: 0 as from 2030
- Other modern Biofuels and Biogas > 3,5%

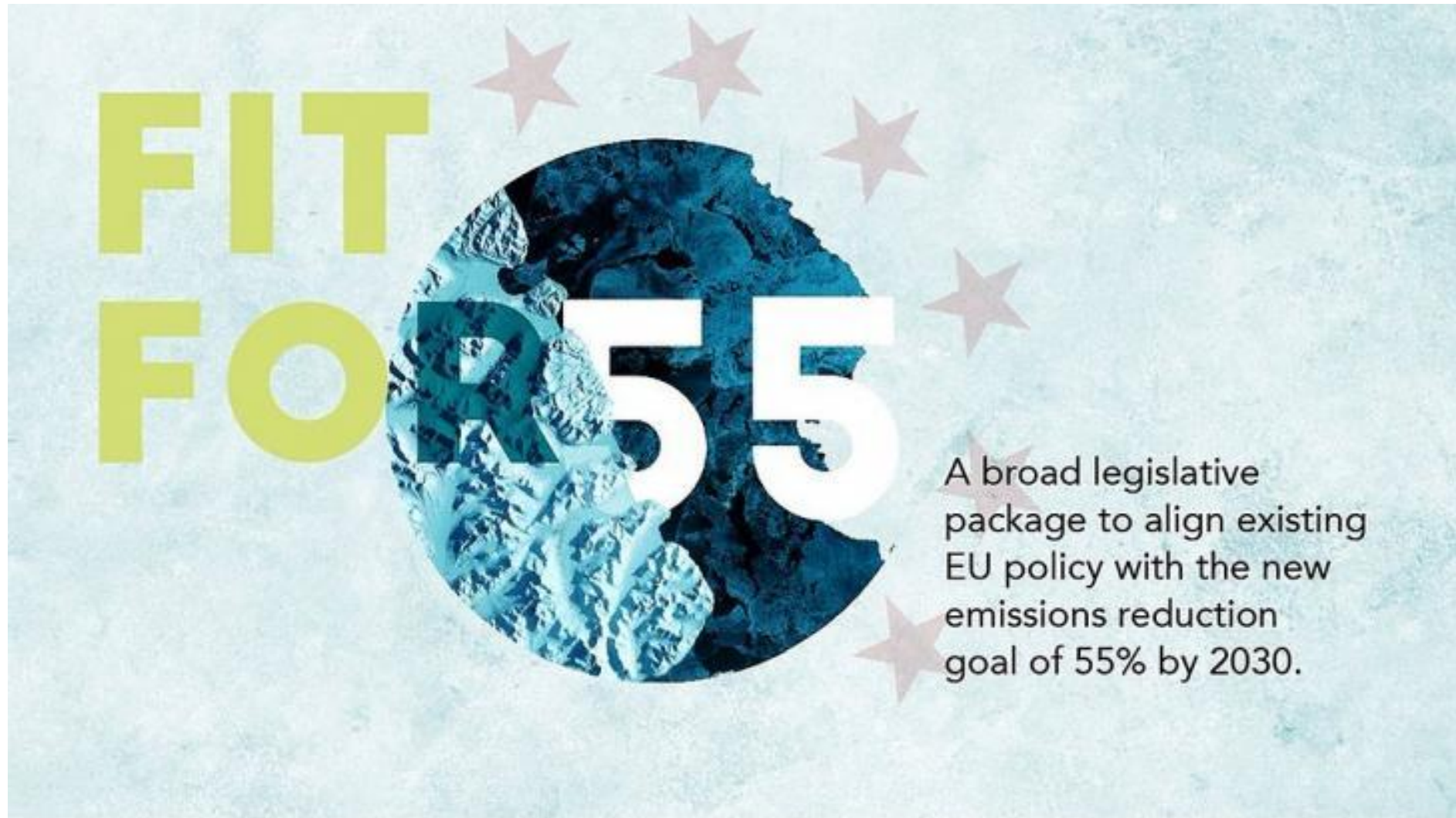
E-ELECTRICITY

HEATING & COOLING

NATIONAL TARGETS and ACTION PLANS



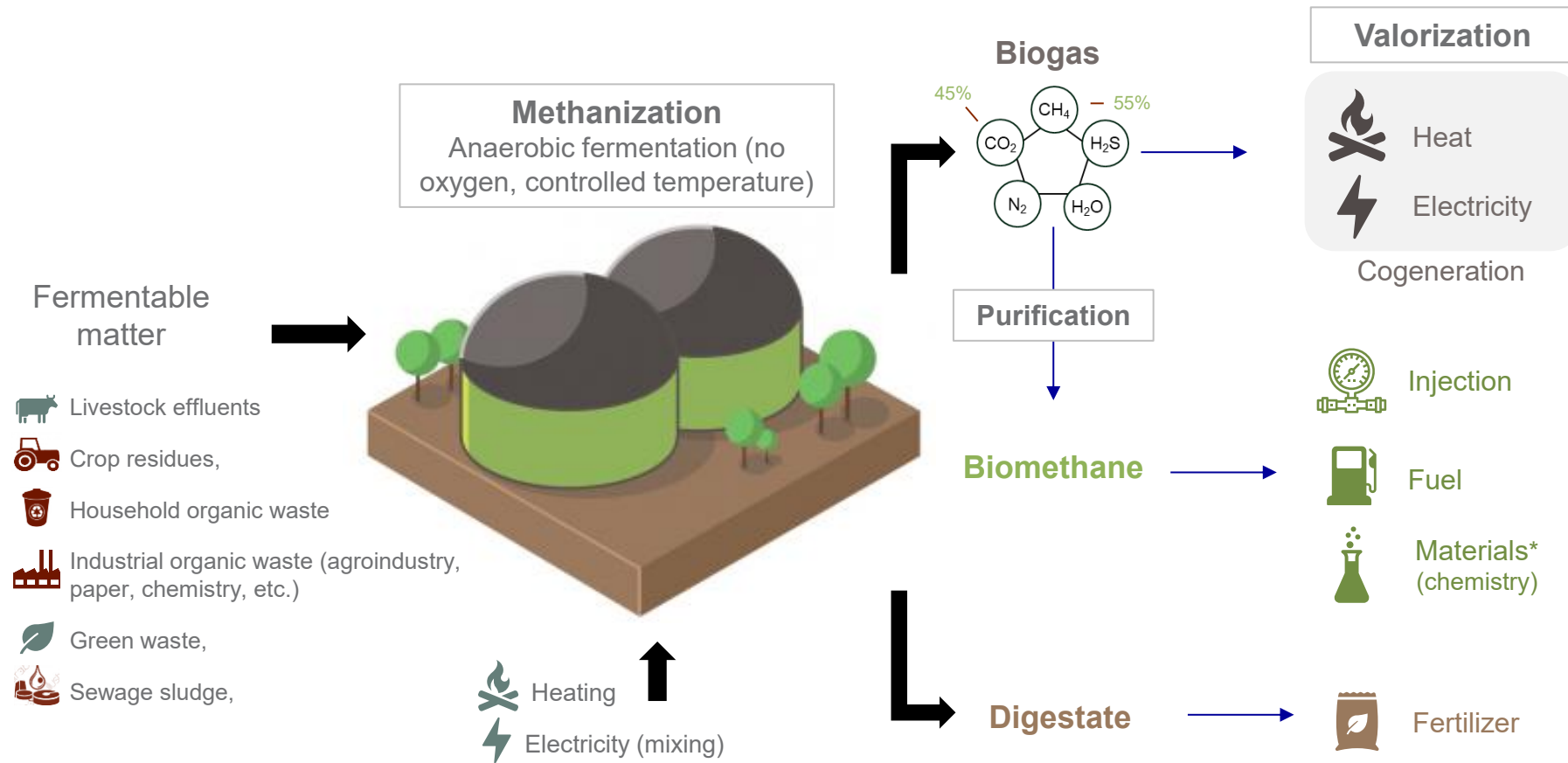
New objectives of European Council 2021 -55% GHG Emissions by 2030 vs 1990



Biogas/Biomethane



Anaerobic digestion process



* as a feedstock for plastic chemicals and source for methanol, ammonia, acetic acid, formaldehyde, and renewable hydrogen



Methanization Unit



Multiple advantages of methanization



- A continuous source of energy
- Load factors:
Solar # 15%
Wind # 24 %



- Share of biogas in total gas consumption should be about 10% in 2030



- A low-carbon gas



- Sustainable source of energy



- Resilience for local territories



- Constant and reliable cash generation



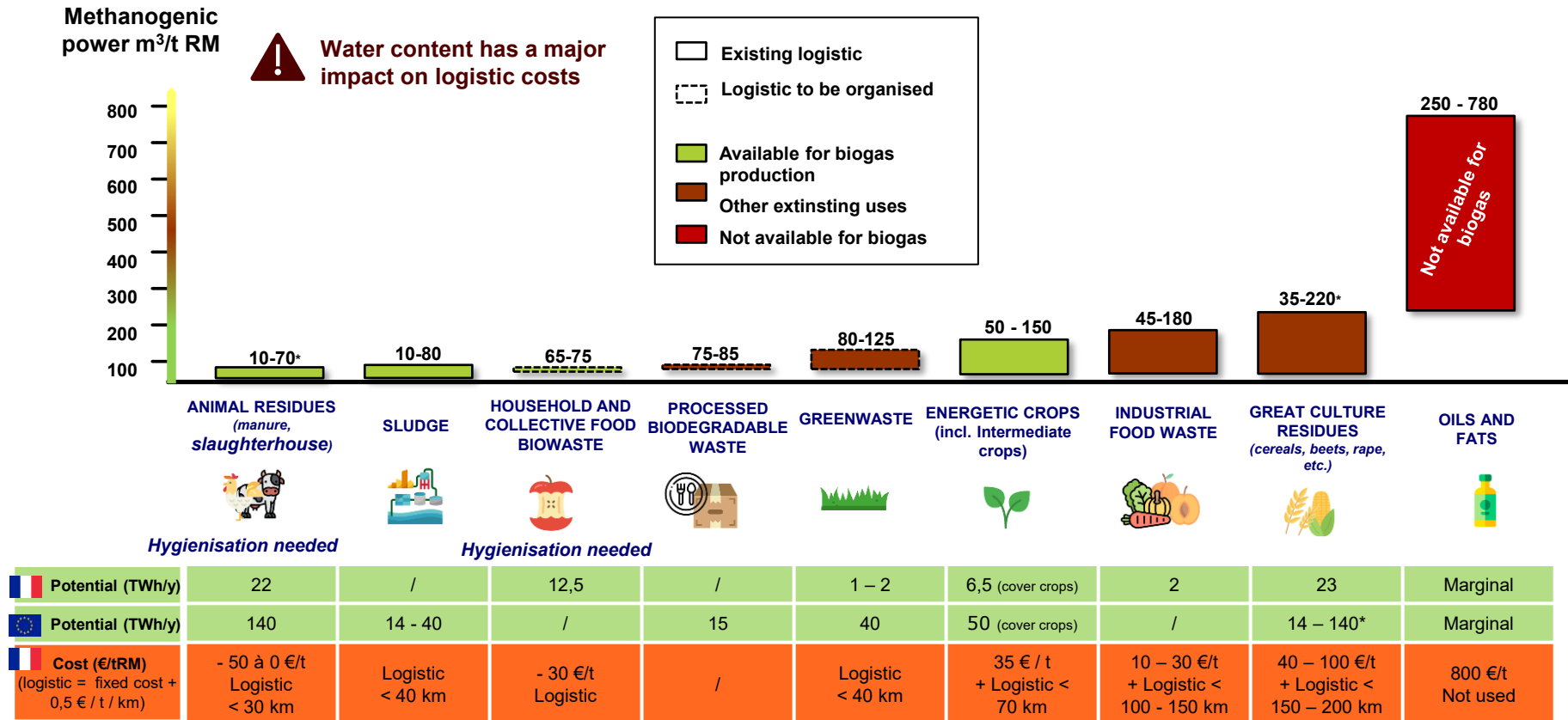
- Multiple sources of revenues:
 - ☐ Reliable and sustainable waste management
 - ☐ Recovery of digestate
 - ☐ Additional revenues for farmers



- Many actors and stakes



Methanogenic Potential depending on Feedstocks



* depending on hypothesis, 5 % to 50 % of great culture residues can be used



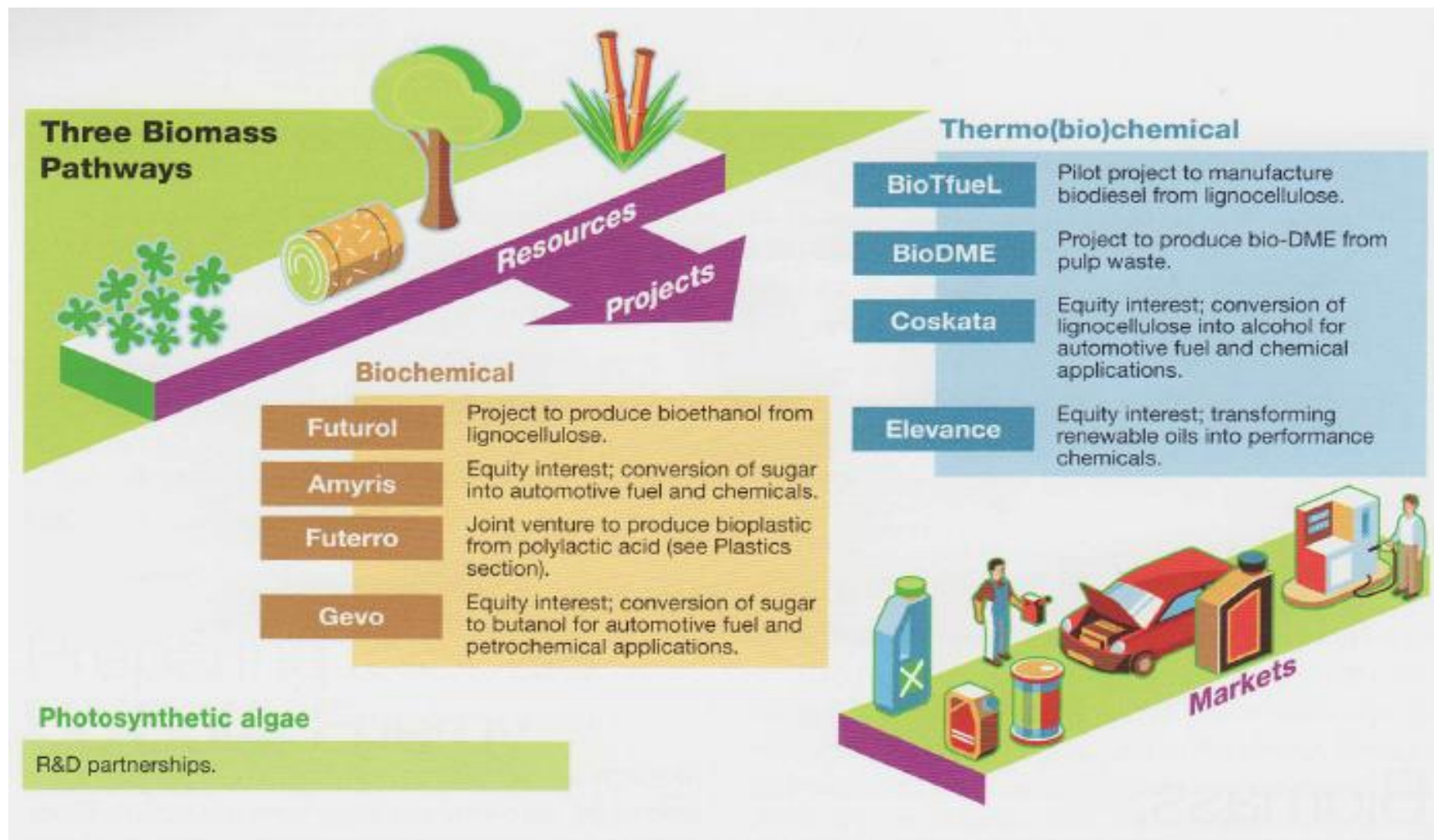
Total acquires Fonroche Biogaz

Paris, January 11, 2021 – Total announces the acquisition of Fonroche Biogaz, a company that designs, builds and operates anaerobic digestion units in France. With close to 500 gigawatt-hours (GWh) of installed capacity, which doubled between 2019 and 2020, Fonroche Biogaz is today the French market leader in the production of renewable gas with more than 10% market share thanks to a portfolio of seven units in operation and a pipeline of four imminent projects.

Drawing on the expertise of its 85 employees, Fonroche Biogaz has developed industrial and technological expertise across the entire renewable gas value chain. Its integration marks a significant step in Total's development on the renewable gas market, with prospects for rapid growth on the French market and for international deployment.



Biomass - Total involvement



R&D Partnerships – Total involvement

Total Energy Ventures: Total's Affiliate in charge of Capital-Risk and Start-ups development.

Since 2008, participations in 18 start-ups companies.

End 2014, Total became shareholder of the Californian Company Nexsteppe, established in 2008, specialized in R&D activities in biofuels and bioproducts.



BioTfuel Project - Total involment

Pilot production of bio-gasoil and bio-kerosene (2nd generation) at Mardyck, North of France (BtL). Feedstock: lignocellulose, wood,....

The pilot production site is located on the site of the ex. Dunkirk refinery.

Process by thermochemical pathway: production of syngas (CO + H₂), followed by Fisher-Tropsch conversion. Gasification unit (15 MW)

Partners: Total, Axens, IFP EN, CEA, Avril & ThyssenKrupp Industrial Solutions

Cost: 180 M€ (Out of which 33 M€ public funds). Construction 24 months, Start-up: 2017.

Full scale potential project: 800 MW, 200 000T/year production?



BioTfuel Project - Total involment

Location:

- Pre-treatment: Avril site in Venette, France
- Gasification, purification and synthesis: Total site in Dunkirk, France

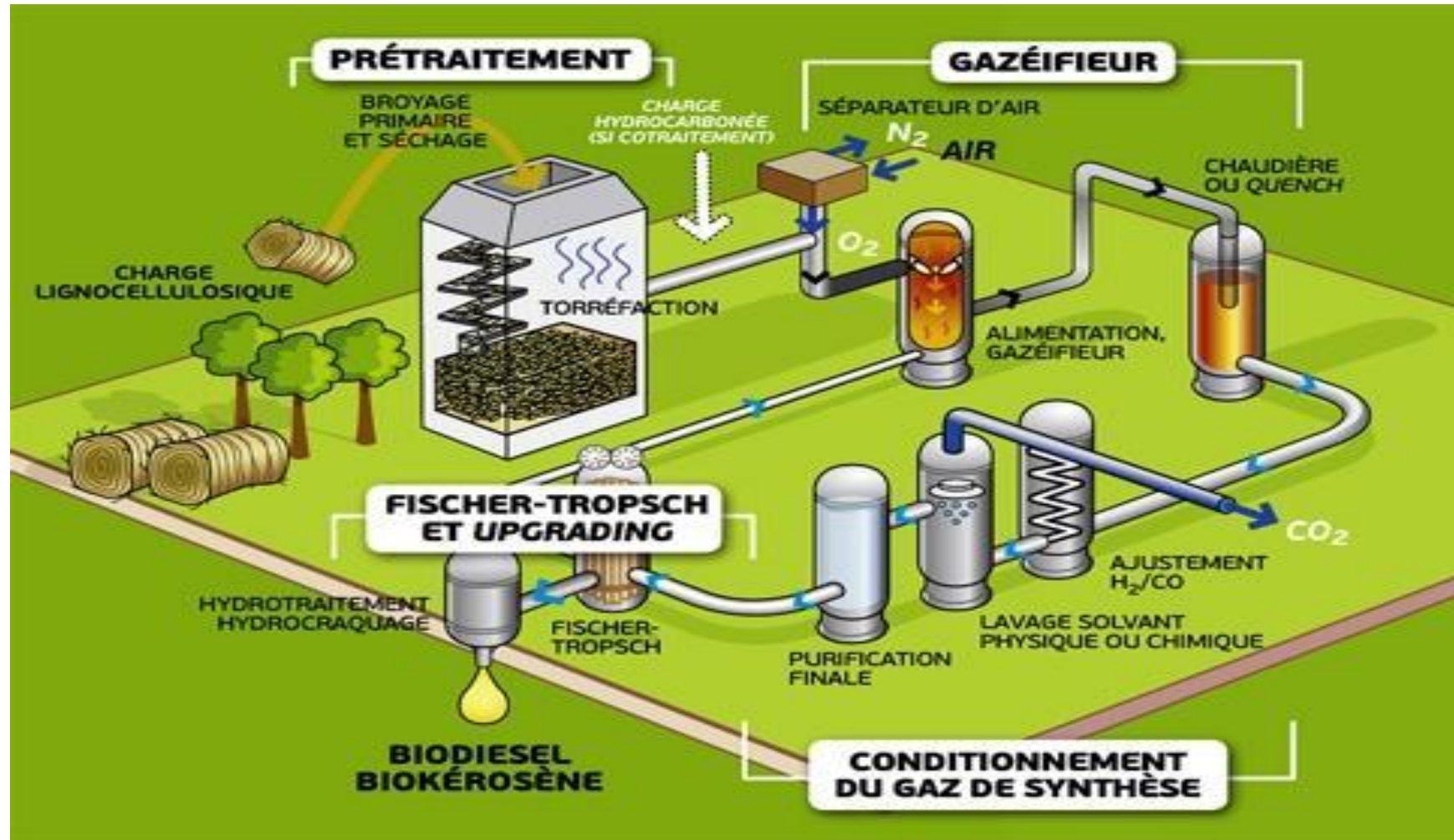
Partners: Axens, CEA, IFP

Energies Nouvelles, Avril, ThyssenKrupp Industrial Solutions, Total

2020 target date to demonstrate the technology



BioTfuel Project – Thermochemical Process



La Mède – Total's first bio-refinery

Location: France

Partners: TotalEnergies

Main activity: renewable diesel production

Other activities: AdBlue® production, logistics and storage hub, training center offering real facilities, solar power generation, planned production of low-carbon hydrogen

Commissioning: 2019

AdBlue® is an additive used to reduce nitrogen oxide (NOx) emissions from diesel engines (trucks and passenger vehicles). The AdBlue® production unit at La Mède produces **50,000 metric tons per year**.

1st world-class biorefinery in France



La Mède – Total's first bio-refinery

- Production of hydrotreated vegetable oil (HVO) biodiesel.
- Raw materials: used oil and vegetable oil.
- Additional production: bio-naphta and bio-jet fuel.
- Expected production: 500000 t/year
- Start of production: 1st quarter 2019

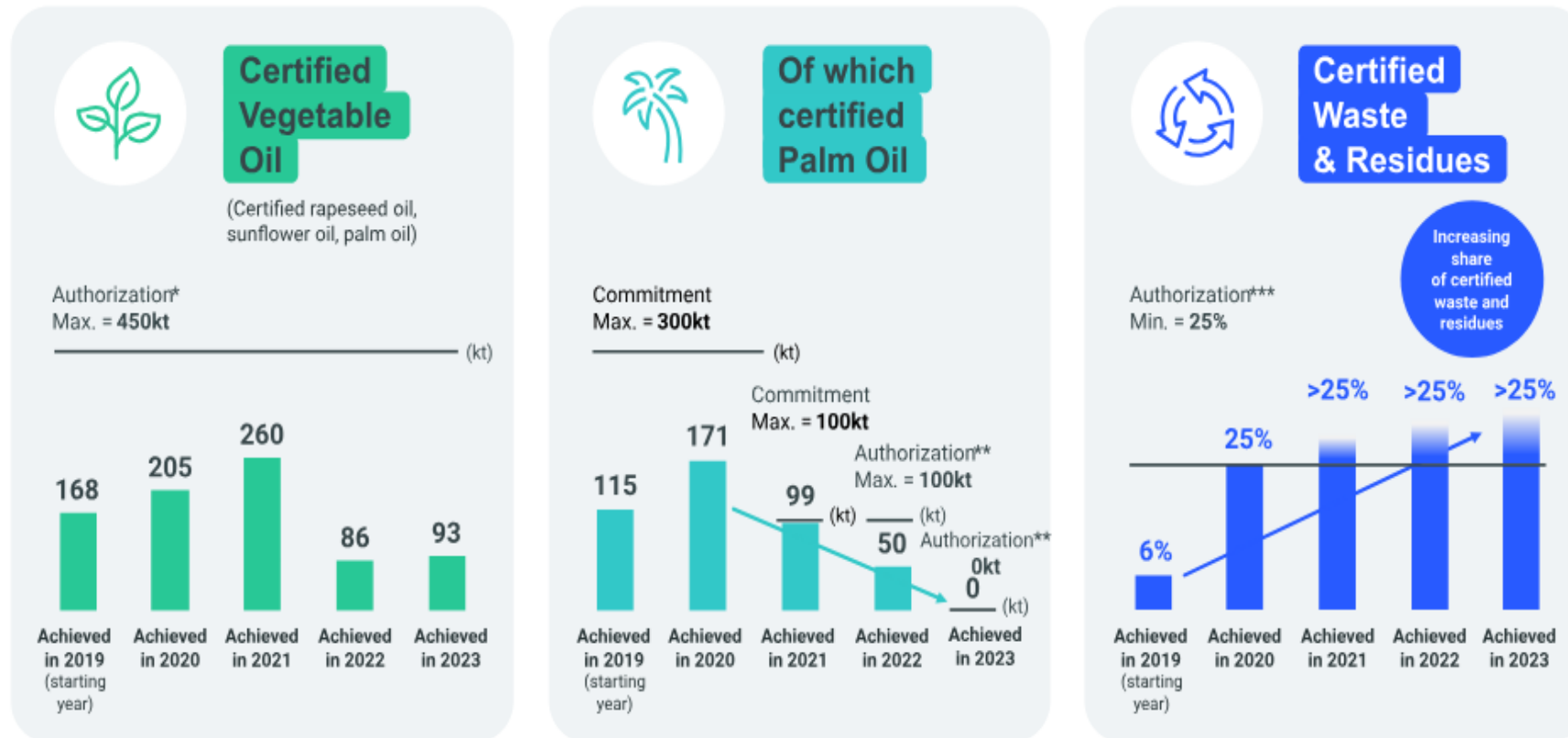


Source: TotalEnergies



La Mède – Total's first bio-refinery

**Diverse biosourced feedstocks
with an increasing share of waste and residues**



* The operating permit from May 16th 2018, updated May 2nd 2022, authorises TERF to process annually 450,000 tons or raw vegetable oil of any kind

** The operating permit from May 16th 2018, updated May 2nd 2022, limits, from 2022, the supply of the biorefinery in certified palm oil to 100 000 tons per year and forbids any palm oil and PFAD from January 1st 2023

*** The operating permit from May 16th 2018, updated May 2nd 2022, authorises TERF to process annually at least 25 % of waste and residues resources (fatty acid distillate, used cooking oil or other triglyceride fatty acid resources listed in Annex IX of the EU Directive on the promotion of the use of energy from renewable sources (RED II) or category 3 animal fat)



Grandpuits – Galaxie/Biojet



**France
Grandpuits
Refinery**

Operated

Production of
Biojet & Biodiesel



CAPEX
376 m€
TTE share
50.1 %



FID
7/26/2022

RFSU
11/2025

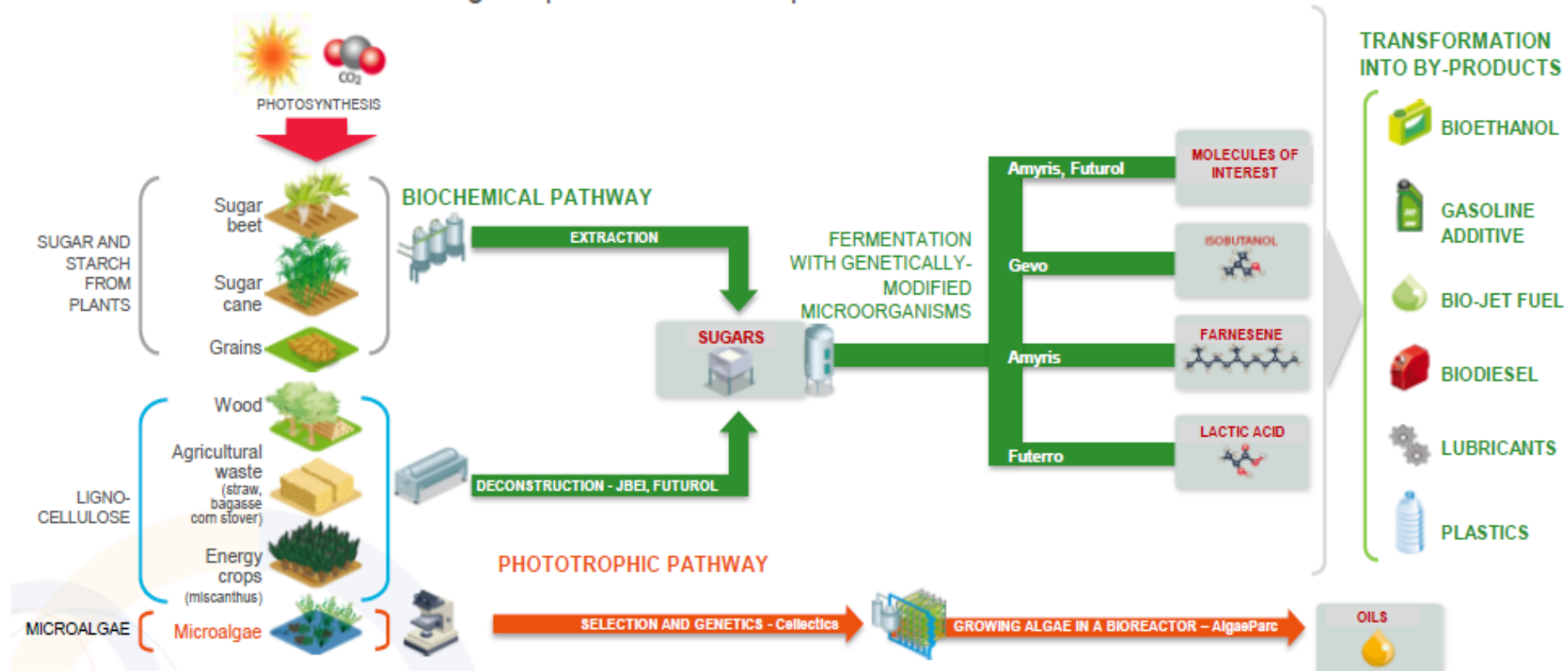
Status
Execution ongoing



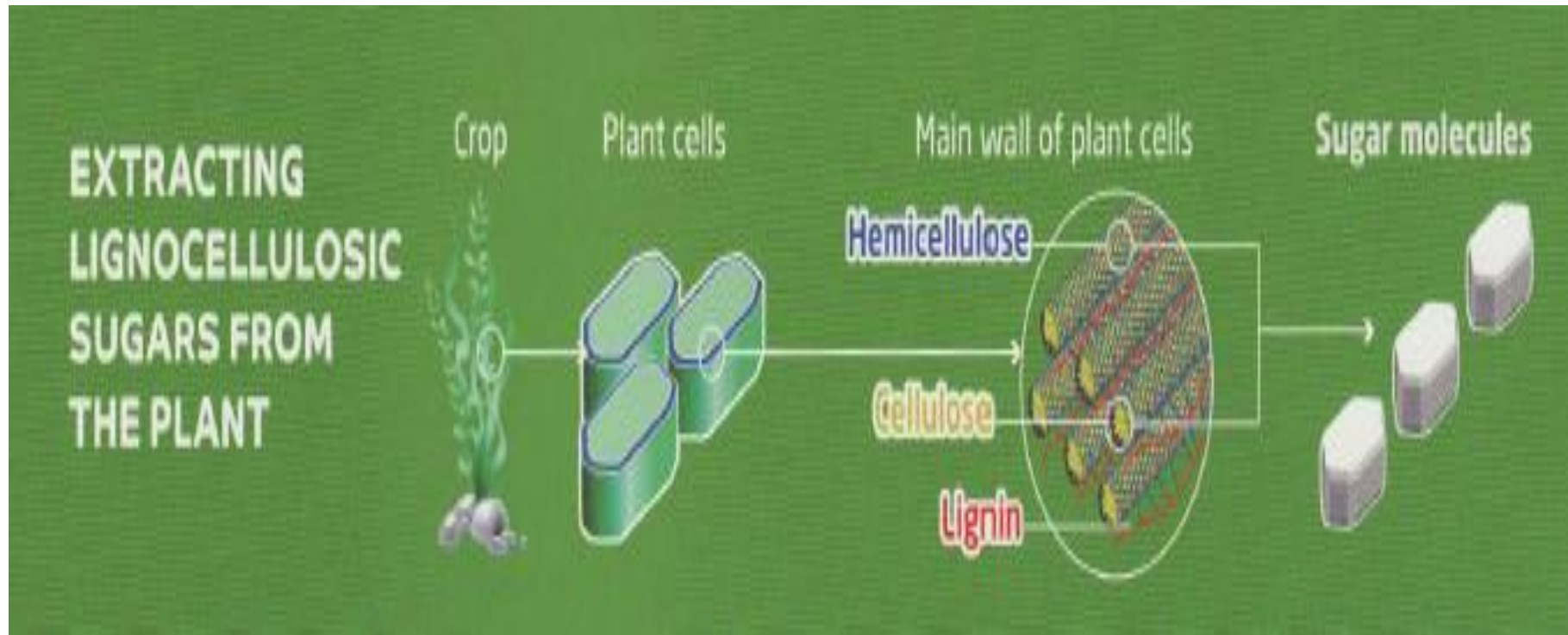
Biomass - Total involvement Biochemical & Phototrophic Pathways

A TWOFOLD INDUSTRIAL CHALLENGE

IDENTIFY the most efficient transformation technologies
DEVELOP a range of products for transportation and chemicals



Biochemical Pathway: getting the energy of sugar



Amyris at a glance

Amyris at a glance

Who is Amyris?

Created in 2003 on the basis of Prof. Jay Keasling research work (UC Berkeley)

Mission: produce terpenes « on demand », based on its versatile synthetic biology platform

Proof of concept with artemisinin (paludism drug) in 2005

Facilities

- 5 R&D and pilot sites (cells to 5 kl - US, Brazil)
- 3 toll production (US – Brazil – Spain)
- Industrial plant planned in 2012 (6x 200 kl - Brazil)

Employees

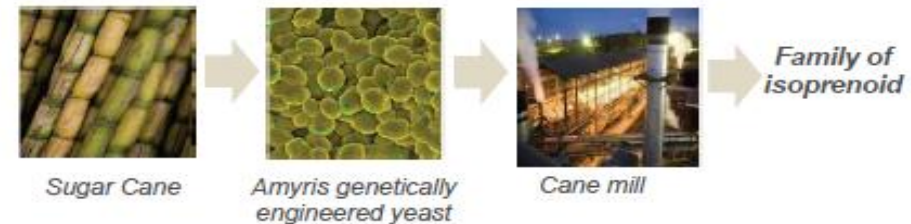
300 employees (~50 in Brazil)

Capital

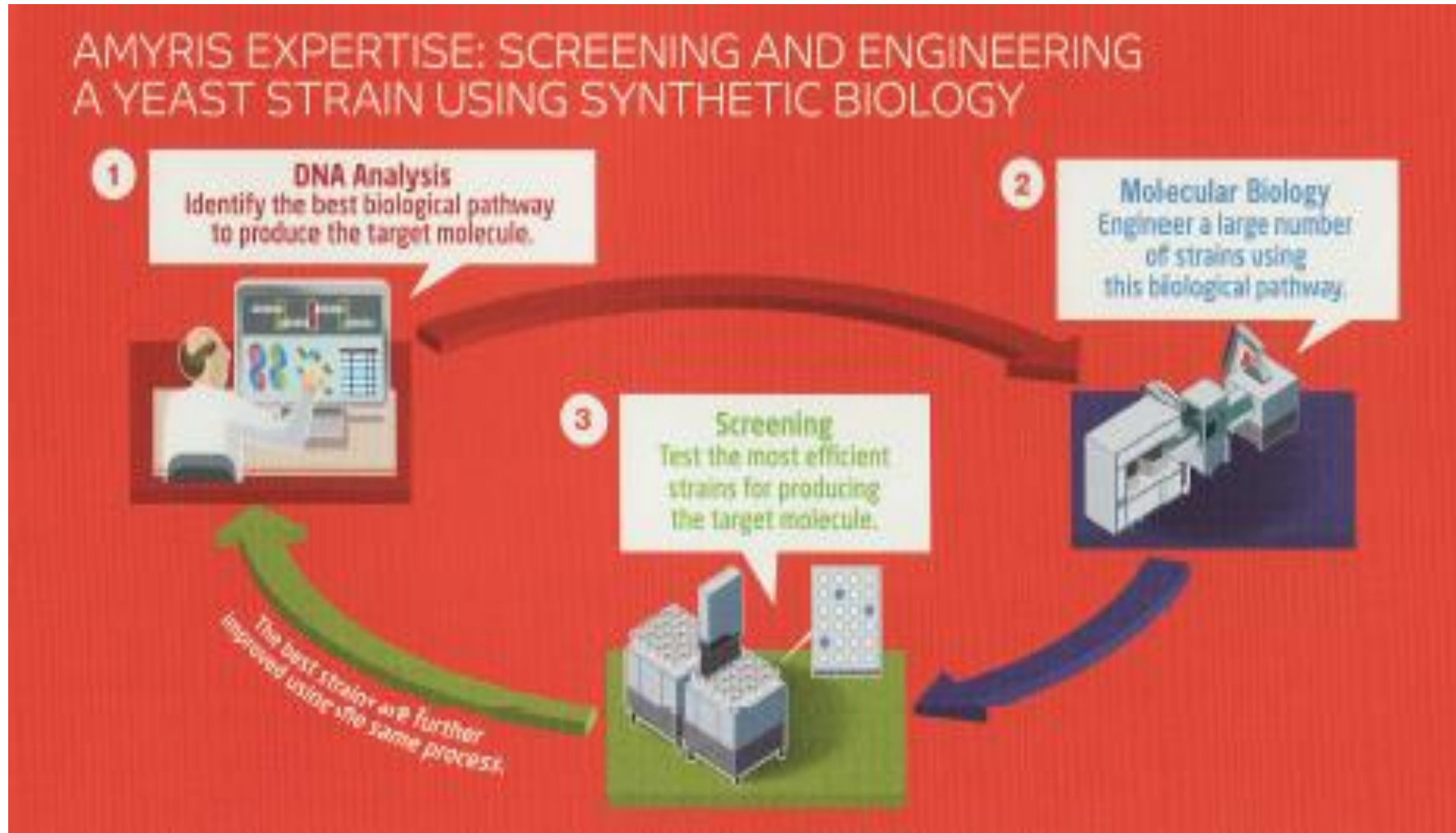
Raised money IPO (Oct. 2010): 85 M\$

IP portfolio

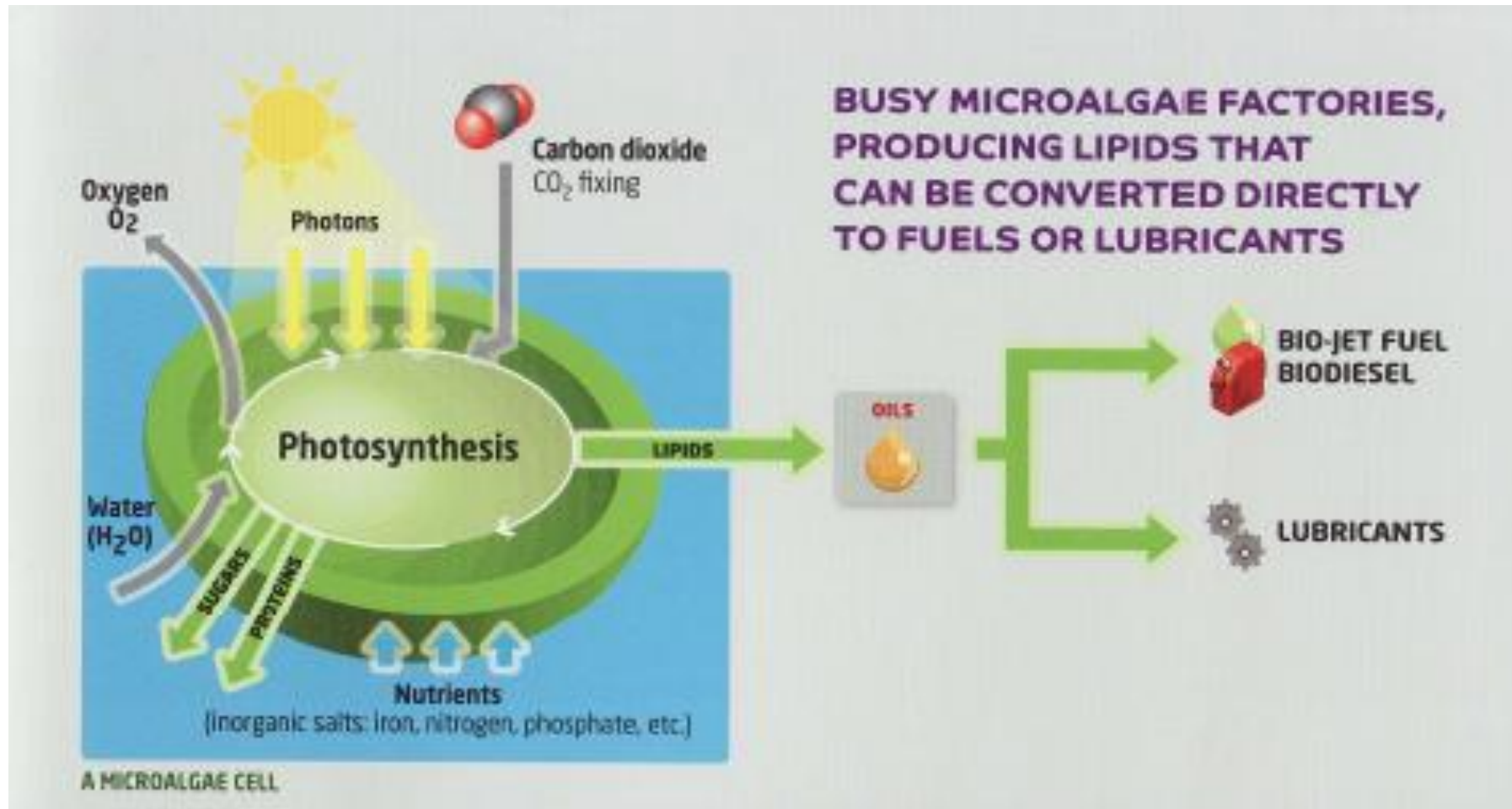
6 granted patents (diesel, jet-fuel, lubricants, adhesives, synthetic biology) and 23 pending applications



Amyris expertise



From microalgae to Molecules of interest



3rd Generation/Microalgae – Pilot Projects

Pilot production of oil products from algae conversion started in Australia. Operator: Muradel

The pilot production site is located at Whyalla, southern Australia.

Process by Green2Black technology, developed by Muradel. Conversion of biomass algae produced on the site, other types of biomass and organic waste into liquid fuel by hydrothermal liquefaction without catalysers.

Cost of the Pilot: 4,4 M\$ financed by Australian Agency for Renewable Energies and other sponsors.

Full scale potential project: Production of 80 Million liters, i.e. 500 000 barrels of petroleum per year in 2019.

Total and Airbus join efforts in R&D. Target: 2020/2030?



Geothermal Energy



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- 2. What about Indonesia ?**



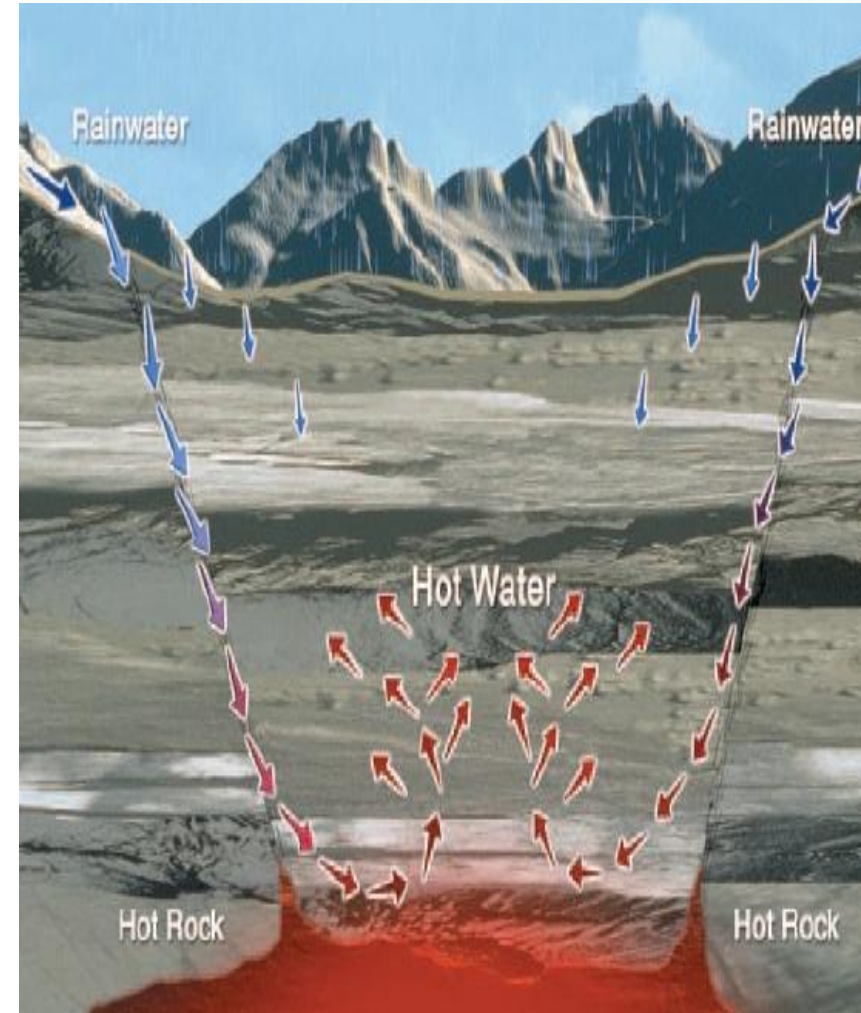
5-1

Geothermal fundamentals



What is Geothermal?

- ◆ **Geo:** earth and **Therme:** heat.
- ◆ **Direct use application:** bathing, cooking, space, heating, etc.
- ◆ **Indirect use as electricity.**
- ◆ **Benefit:** clean, renewable and environment-friendly sources.
 - CO₂ credit
- ◆ **Early detection of potential location**
 - surface manifestation
 - Hot spring/pools/lake, steaming ground, geyser, etc.
 - associated with presence of volcanic activity.

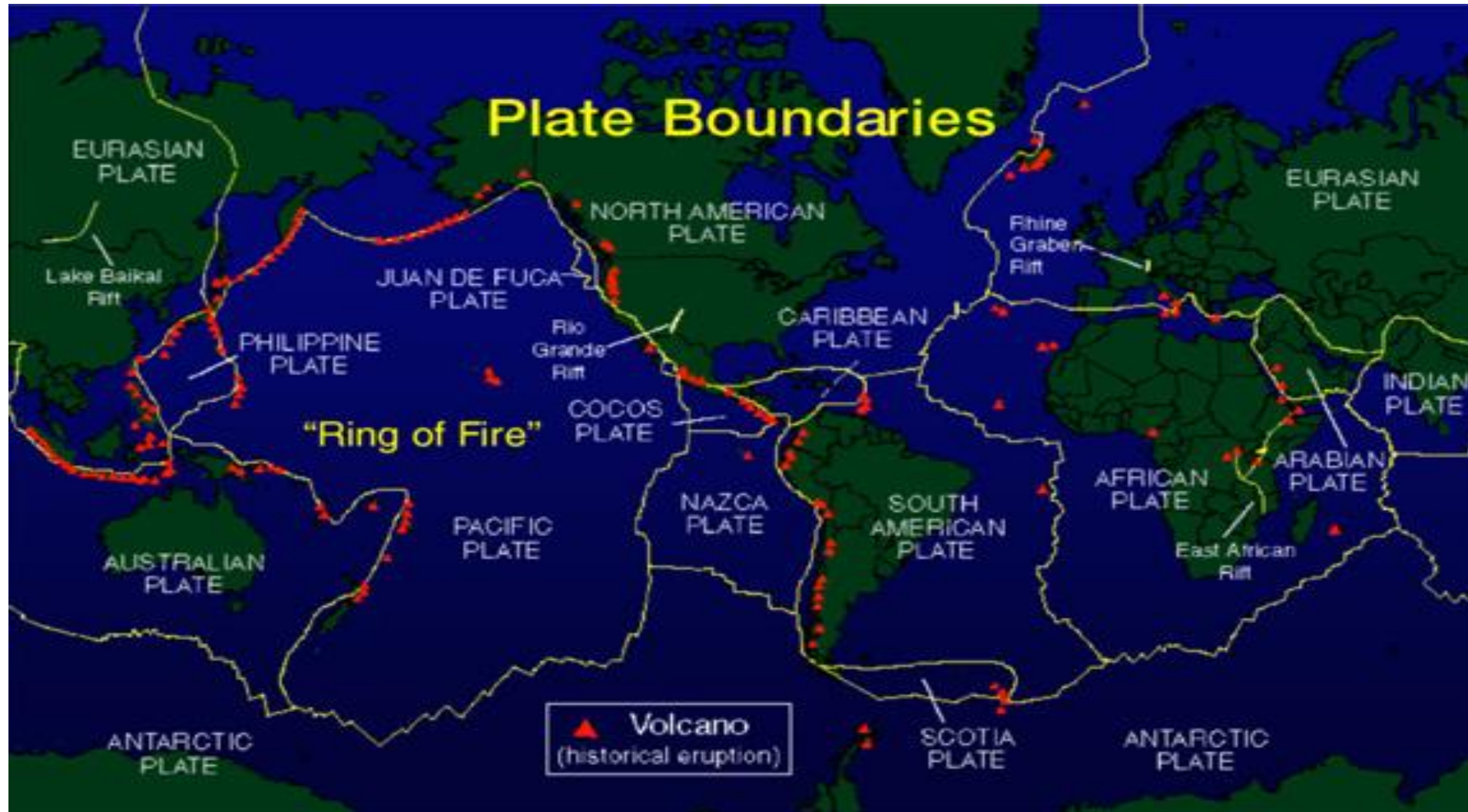


The four categories of geothermal energies for three different usages

- ◆ The « classical » steam or hot water geothermal.
(associated with volcanic activity)
 - ◆ The low temperature geothermal energy
 - ◆ The surface geothermal energy = heat pumps
 - ◆ The dry rock or deep geothermal energy
-
- ◆ Ground sources Heat Pumps
 - ◆ Direct Heat Usage
 - ◆ Electricity Generation

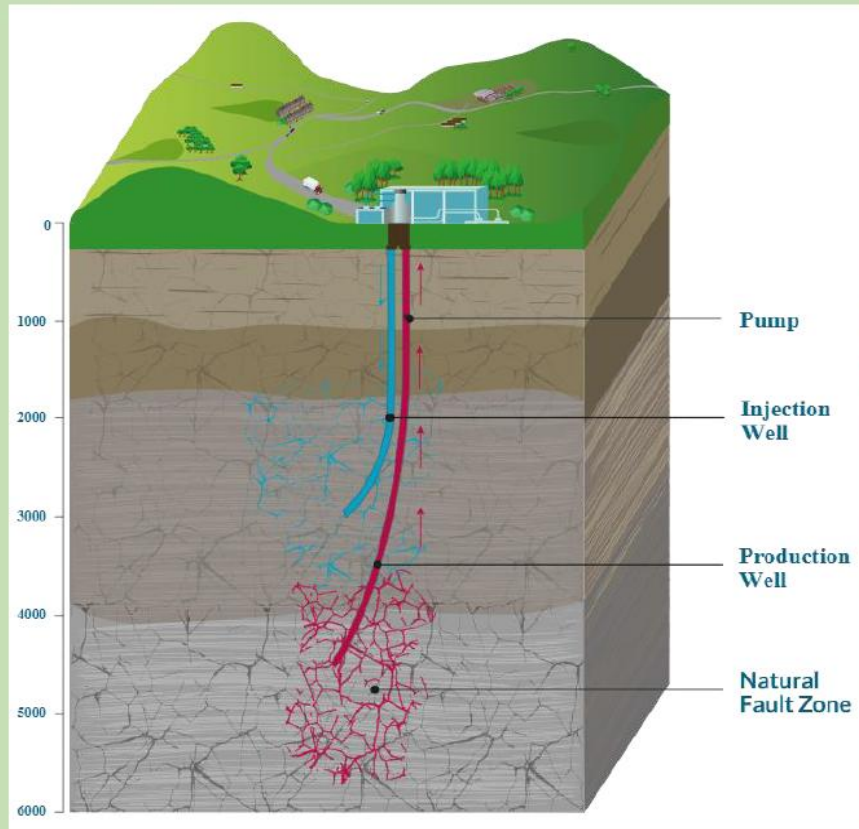


World classical geothermal



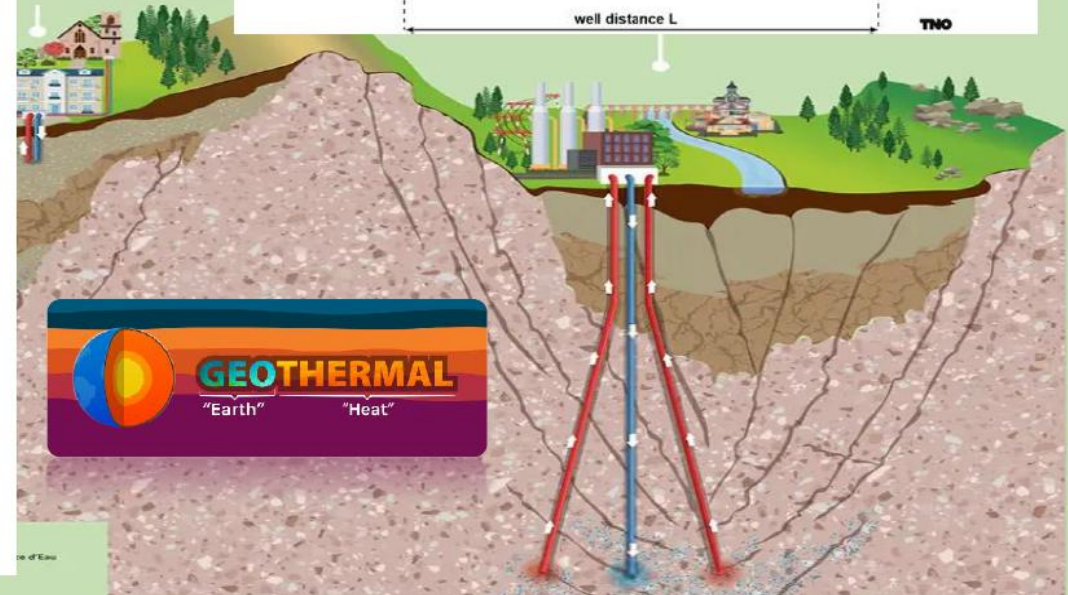
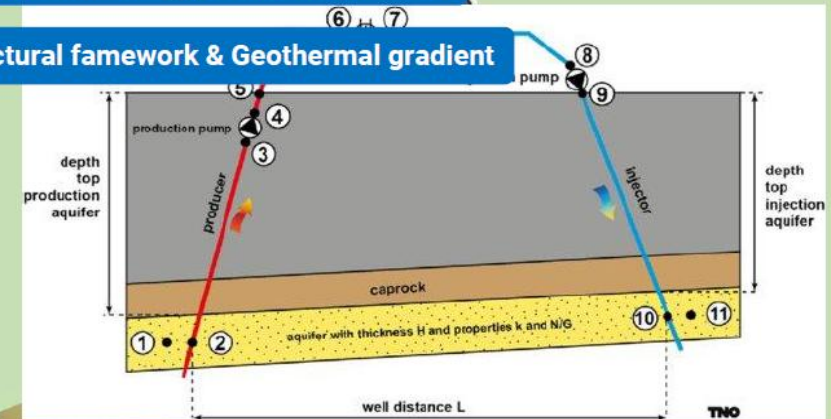
Geothermal Energy – Main types

Geothermal energy Main types



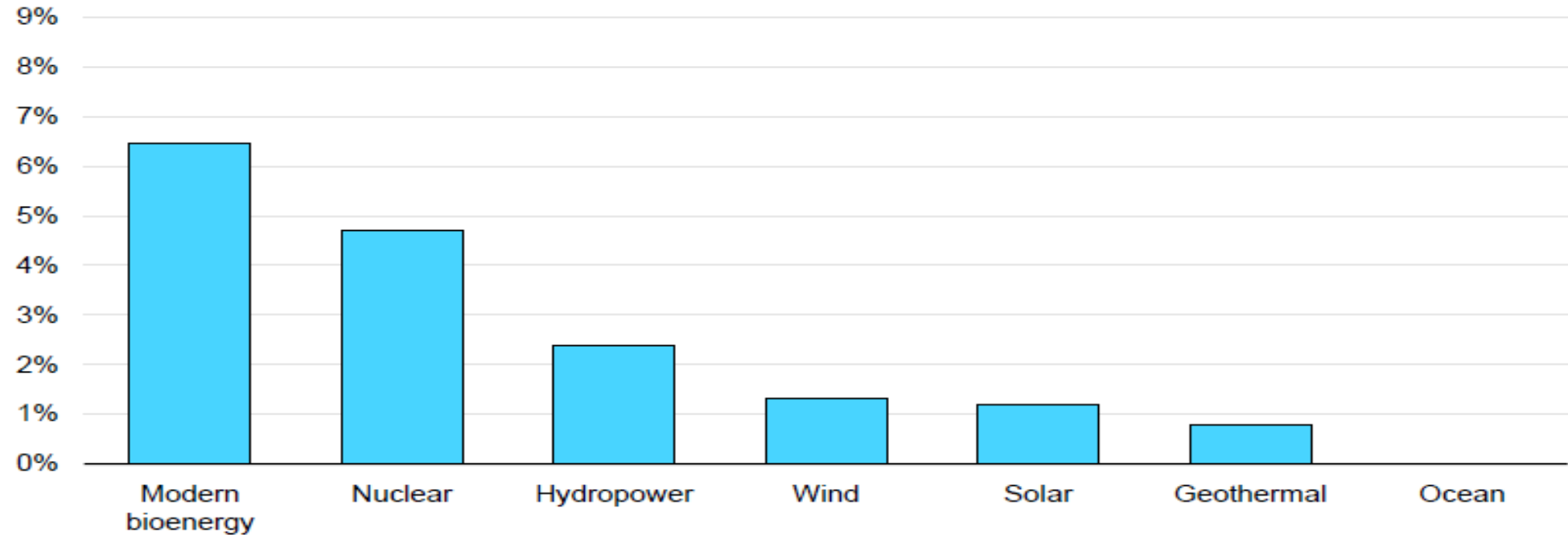
Key parameters: Aquifer thickness, permeability & NTG

Key parameters: Structural framework & Geothermal gradient



Geothermal in total Energy Demand – less than 1%

Shares of clean energy technologies in total energy demand, 2023



IEA. CC BY 4.0.

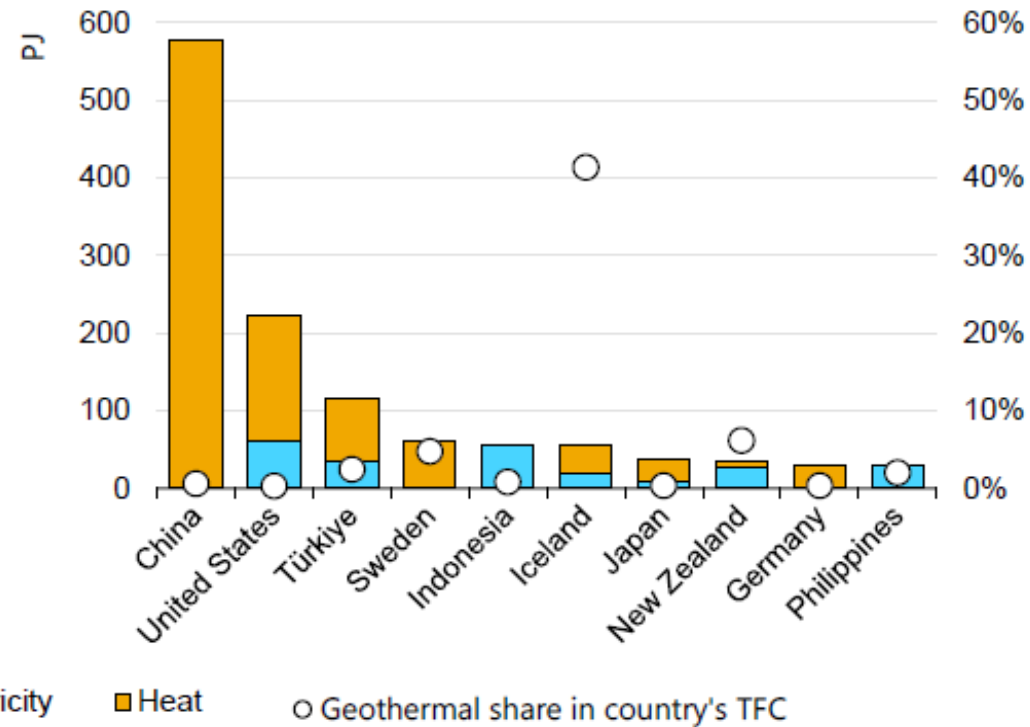
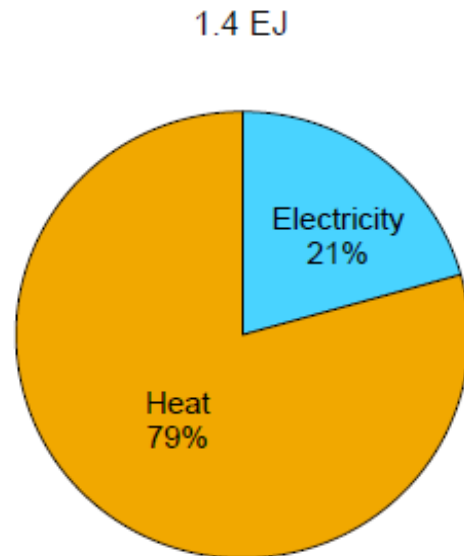
Notes: Values exclude geothermal heat harnessed by ground-source heat pumps, which is not included in official IEA statistics. However, estimates of geothermal heat from ground-source heat pumps derived from modelling are included in the heat discussion below, as well as in the outlook section. "Modern bioenergy" includes all bioenergy in the form of liquids (ethanol, biodiesel and biojet fuel), gases (biogas and biomethane) and solids, excluding the traditional use of solid bioenergy such as a three-stone fire or basic improved cook stoves (ISO tier < 3), often with no or poorly operating chimneys.

Source: IEA (2024), [World Energy Balances](#).



Geothermal Energy Consumption by application & countries

Total final geothermal energy consumption by application, world (left), and top 10 consuming countries (right), 2023



IEA. CC BY 4.0.

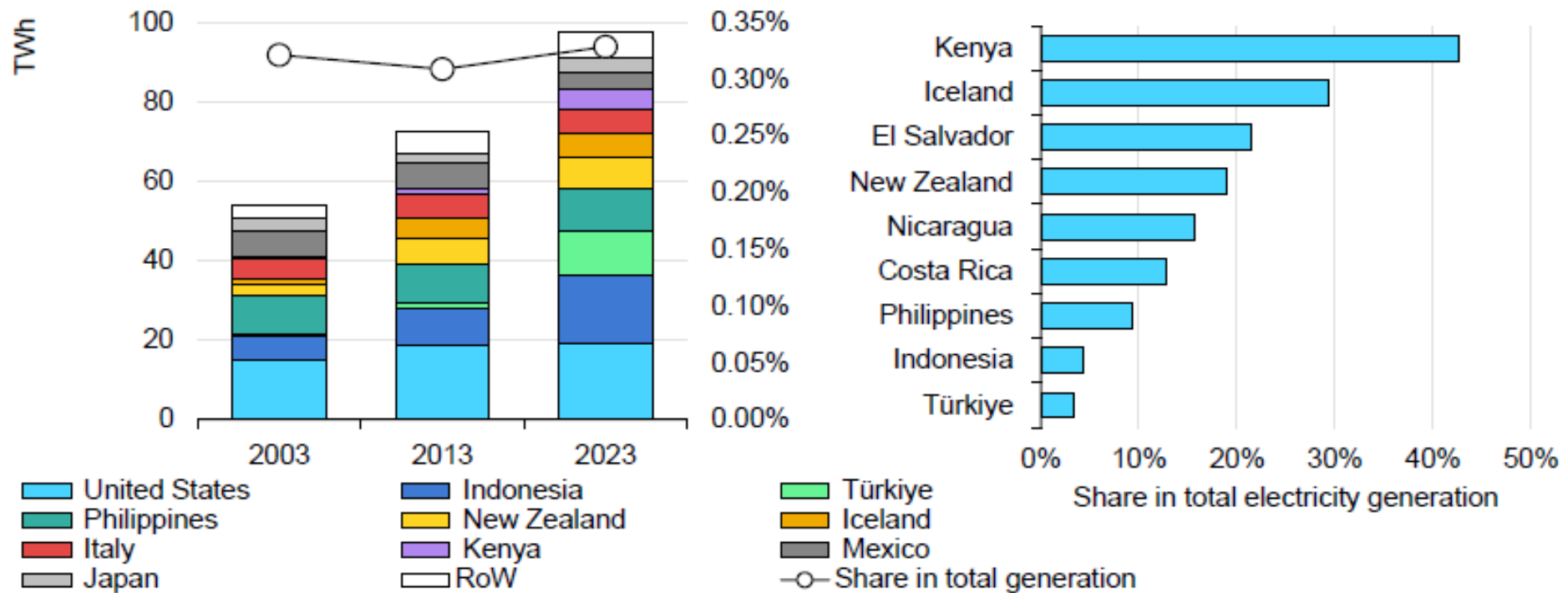
Notes: TFEFC = total final energy consumption. EJ = exajoule. PJ = petajoule. Heat consumption includes an estimate for ground-source heat pumps that is not included in IEA direct heat consumption statistics.

Sources: IEA (2024), [World Energy Balances](#); IEA (2024), [World Energy Outlook 2024](#).



Geothermal Electricity Generation by countries – Kenya n°1

Geothermal electricity generation, 2003-2023 (left) and geothermal shares in selected countries' electricity supplies, 2023 (right)



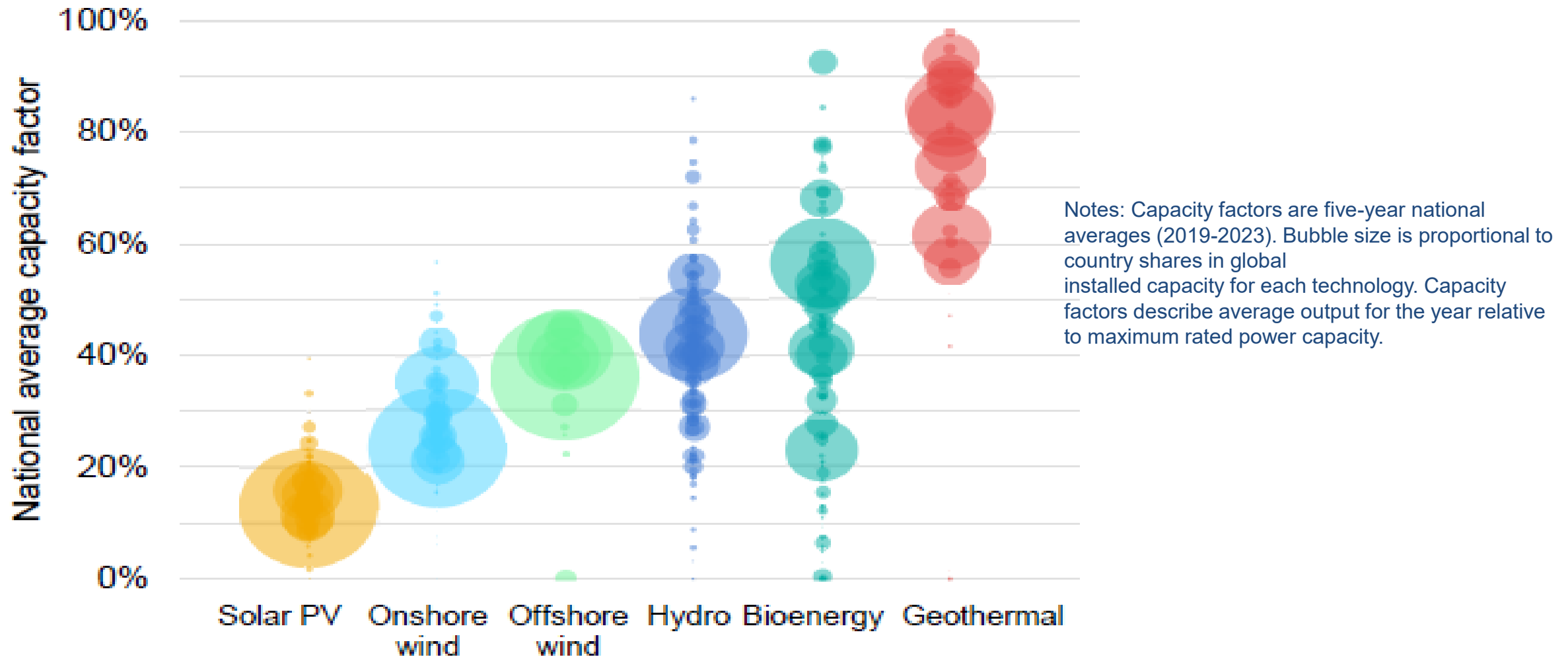
IEA. CC BY 4.0.

Note: RoW = rest of world.

Source: IEA (2024), [World Energy Balances](#).

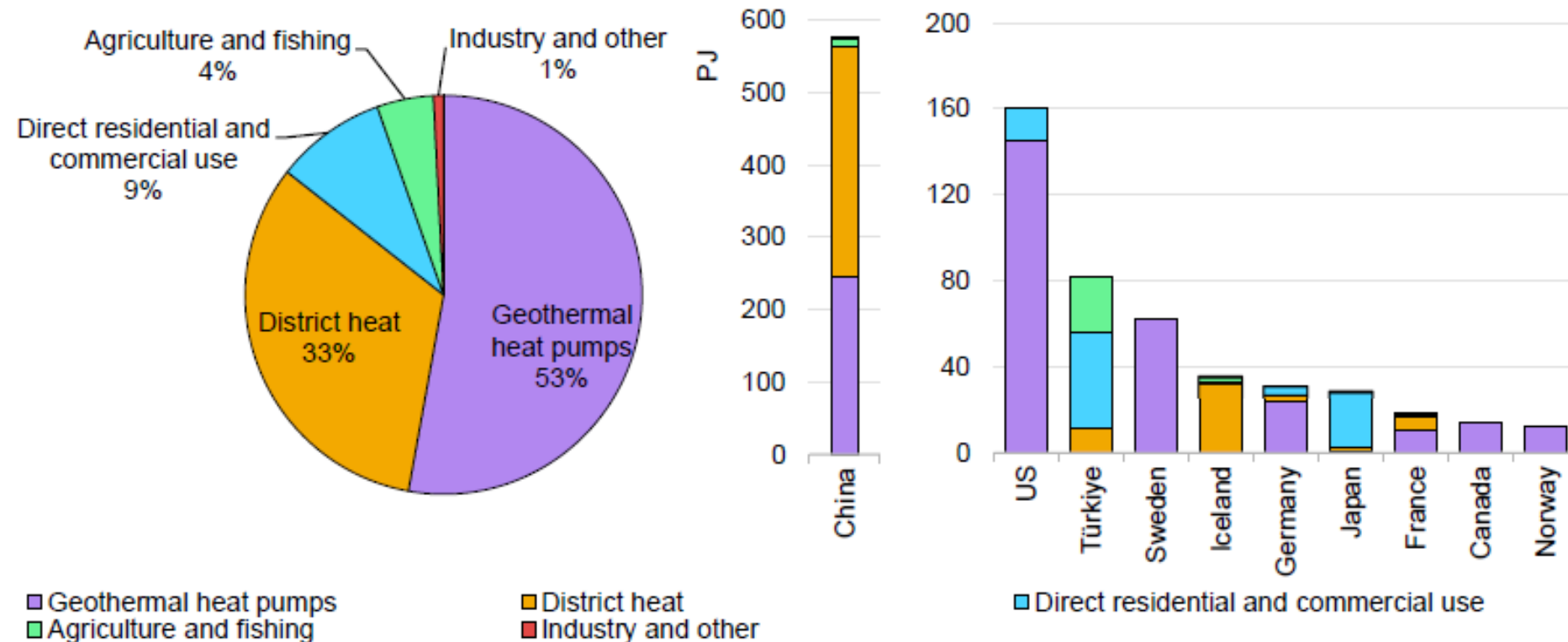


Geothermal Capacity Factors among the best worldwide



Geothermal Energy used for heating & cooling

Direct and indirect geothermal energy consumed for heating and cooling by application, world (left) and top 10 consumers (right), 2023



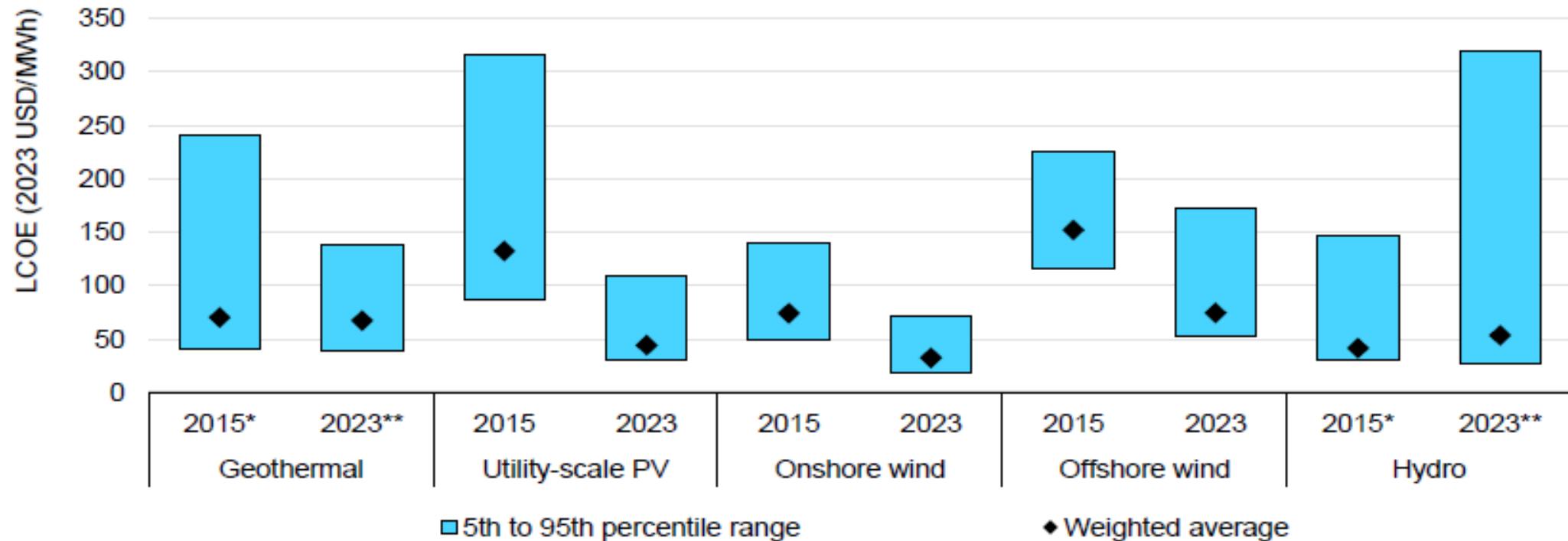
IEA. CC BY 4.0.

Note: "Direct residential and commercial use" includes space and water heating, bathing and swimming, and snow-melting.



Geothermal Energy LCOE is competitive

Typical LCOE range for renewable power technologies, 2015-2023



IEA. CC BY 4.0.

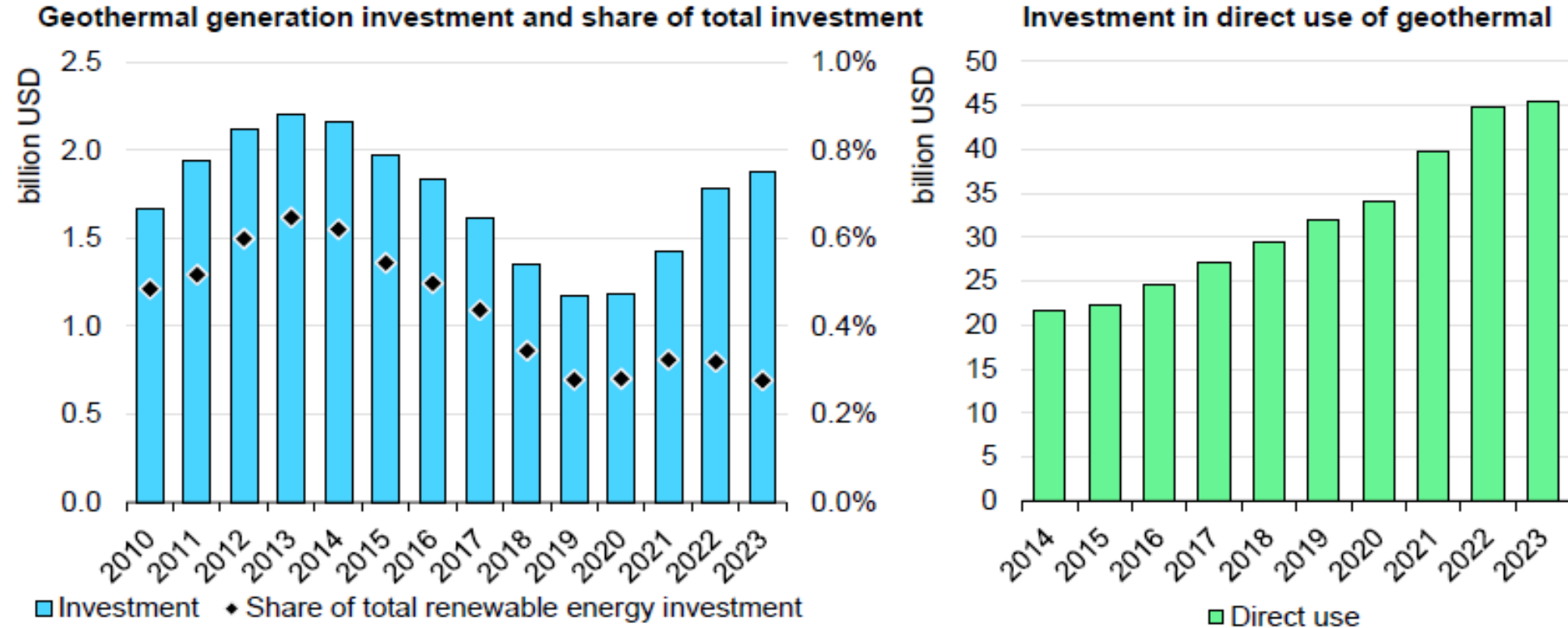
*Projects commissioned in 2010-2015. **Projects commissioned in 2019-2023.

Sources: IEA analysis based on data from IRENA.



Geothermal Energy Investments is much more important for direct use than for Electricity Generation

Global investments in geothermal power plants and in direct use, 2010-2023



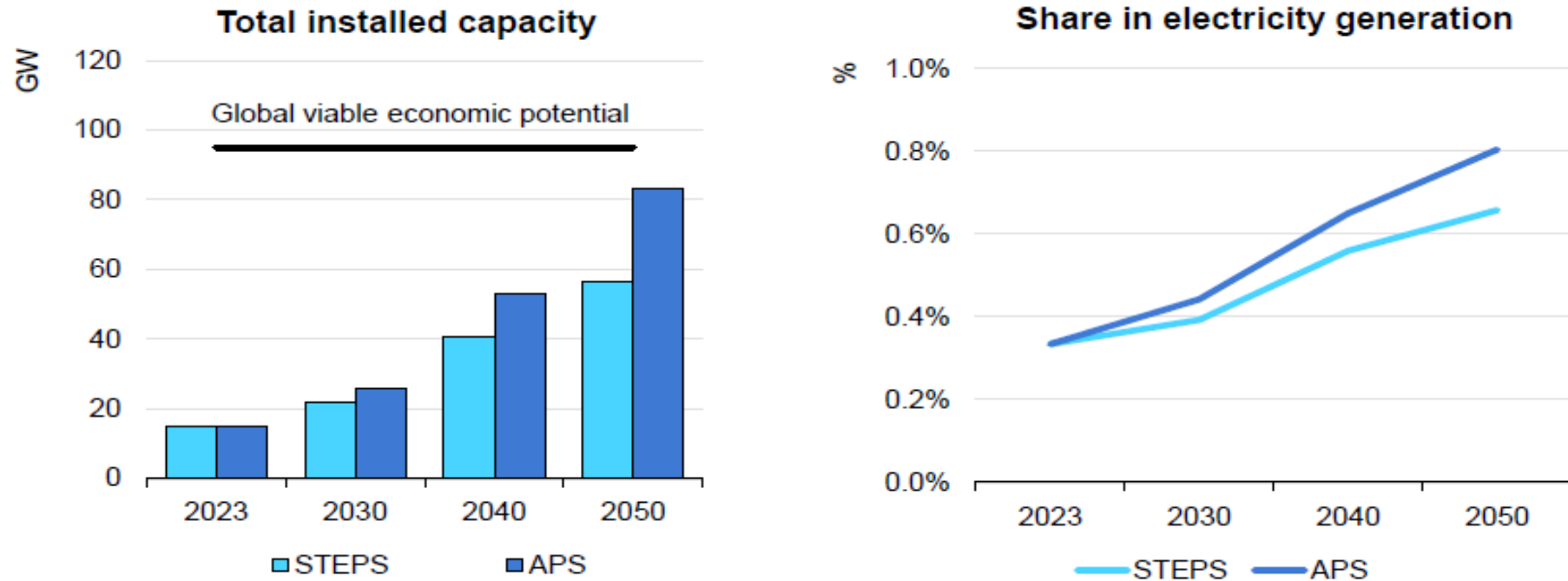
IEA. CC BY 4.0.

Source: Analysis based on IEA (2024), [World Energy Investment 2024](#).



Geothermal Power Capacity for Electricity Generation is planned to increase substantially

Projected global conventional geothermal power capacity and electricity generation shares by scenario, 2023-2050



IEA. CC BY 4.0.

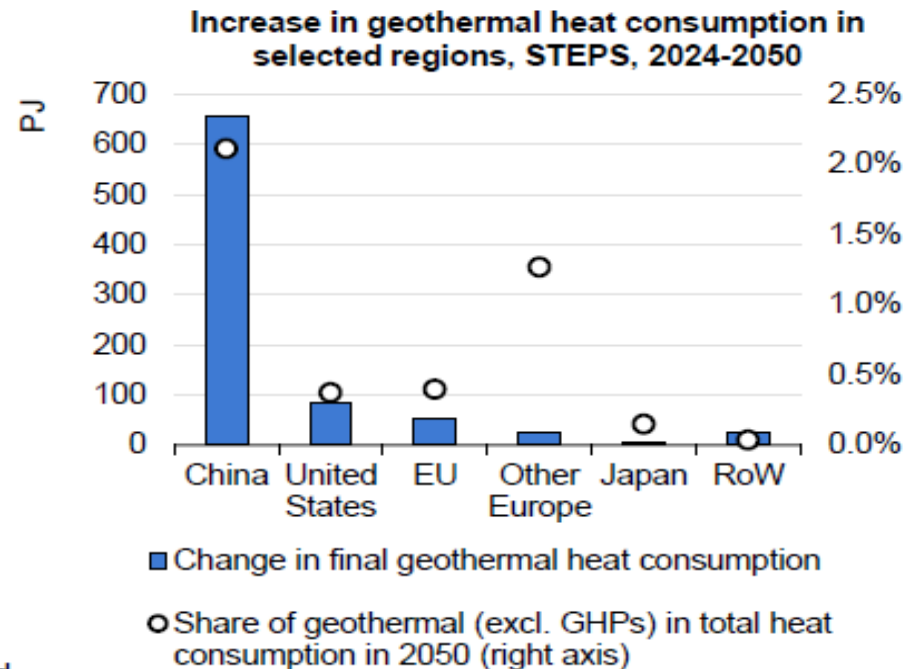
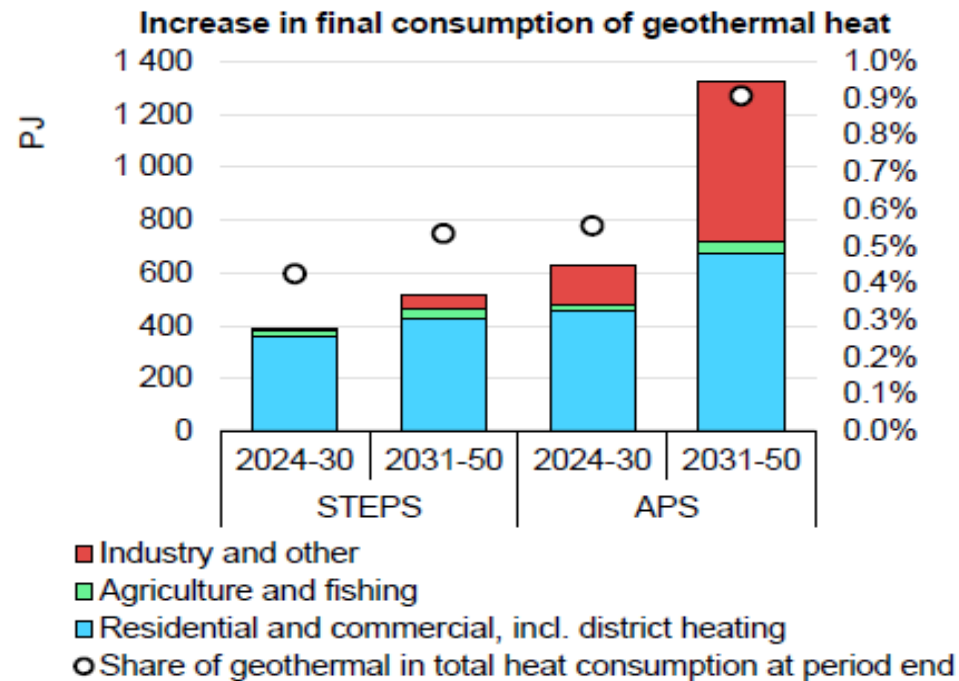
Notes: STEPS = Stated Policies Scenario. APS = Announced Pledges Scenario.

Source: IEA (2024), [World Energy Outlook 2024](#).



Geothermal Energy use for Heating is planned to increase substantially

Increases in direct conventional geothermal use in the Stated Policies and Announced Pledges Scenarios, 2023-2050



IEA. CC BY 4.0.

Notes: STEPS = Stated Policies Scenario. APS = Announced Pledges Scenario. RoW = rest of world. GHPs= geothermal heat pumps. Residential and commercial heat figures exclude geothermal heat pumps.

Source: IEA (2024), [World Energy Outlook 2024](#).



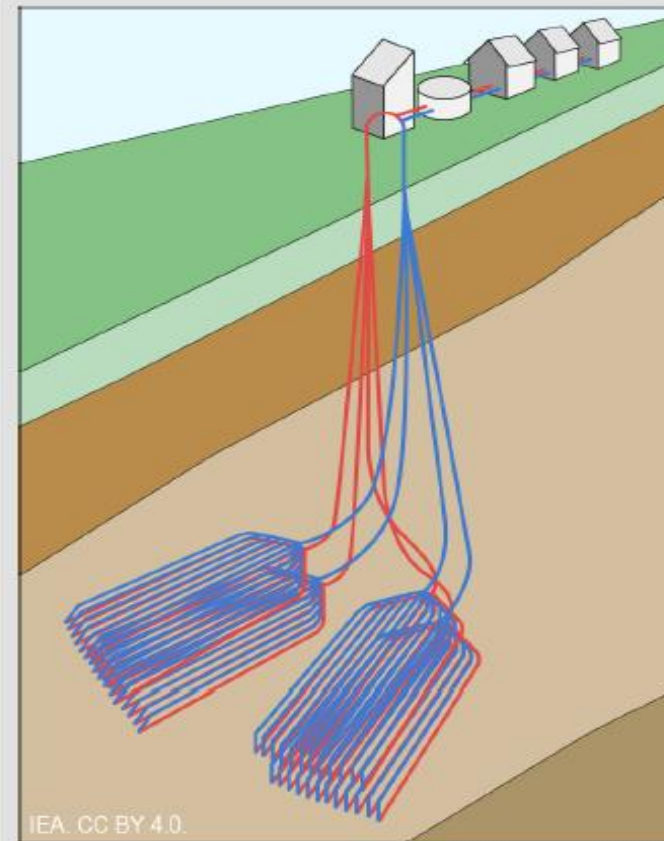
Technology

Example of a Closed-Loop Geothermal system

[Eavor-Europe](#)
(Eavor)

- **Location:** Geretsried, Bavaria, Germany
- **Completion date:** Scheduled for 2027 for the overall project – drilling started in 2023 and power generation from the first heat exchanger is expected to start in the first half of 2025, while drilling for other exchangers continues.
- **Design:** Four subsurface heat exchangers (called “Eavor-Loops”), each formed by twenty-four 3 500 m-long lateral wells drilled from the base of two 4 500 m-deep vertical wells and connected in pairs (totalling about 320 km of drilling length for the whole project), using water as working fluid, circulated by thermosiphon.

Expected output: 64 MW_{th} / 8.2 MW_e



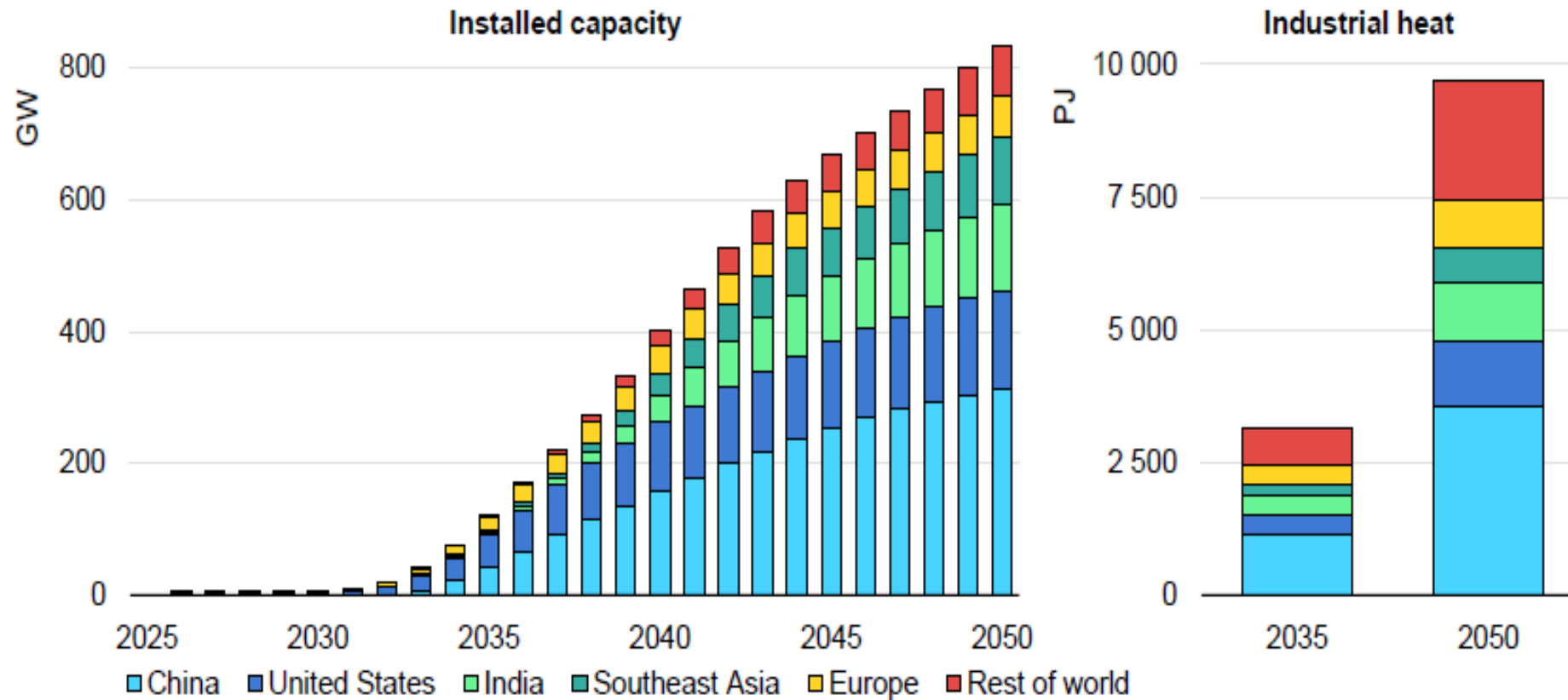
IEA. CC BY 4.0.

Source: Eavor Technologies, 2024



Market potential for next-generation Geothermal Energy Questionable?

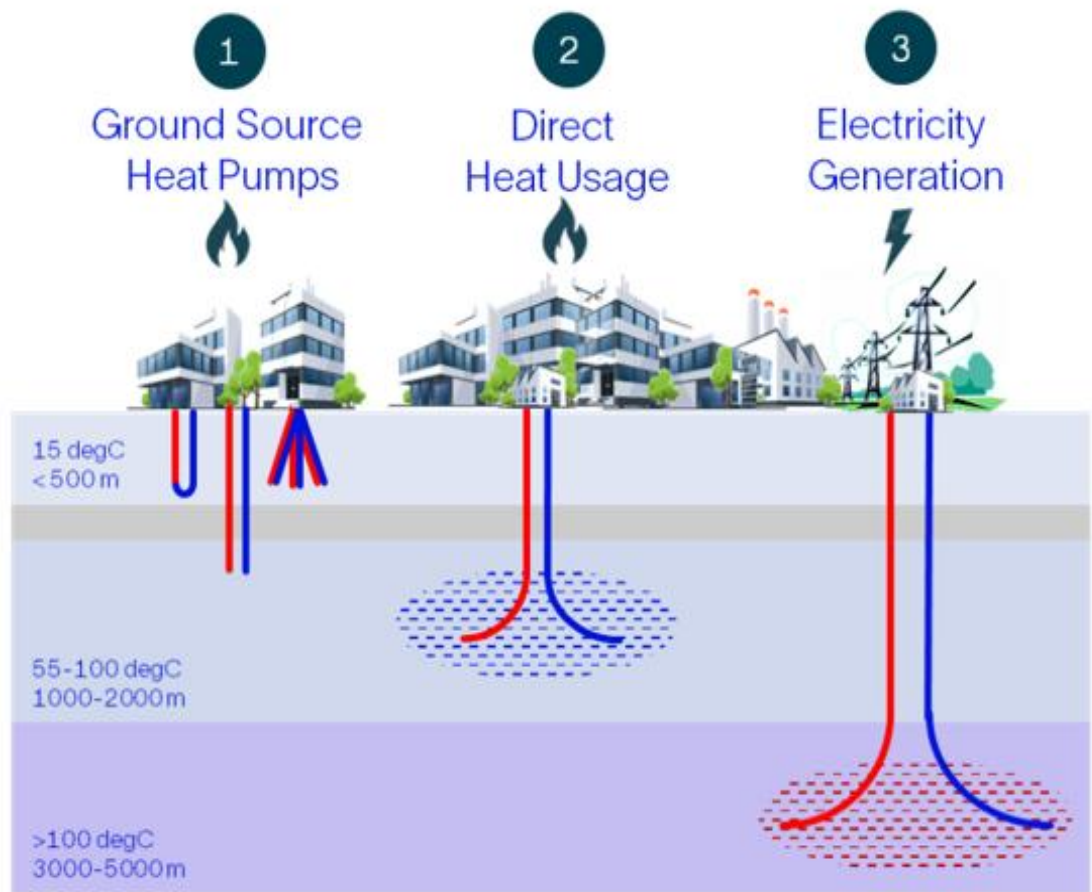
Market potential for next-generation geothermal power capacity and industrial heat by region, 2025-2050



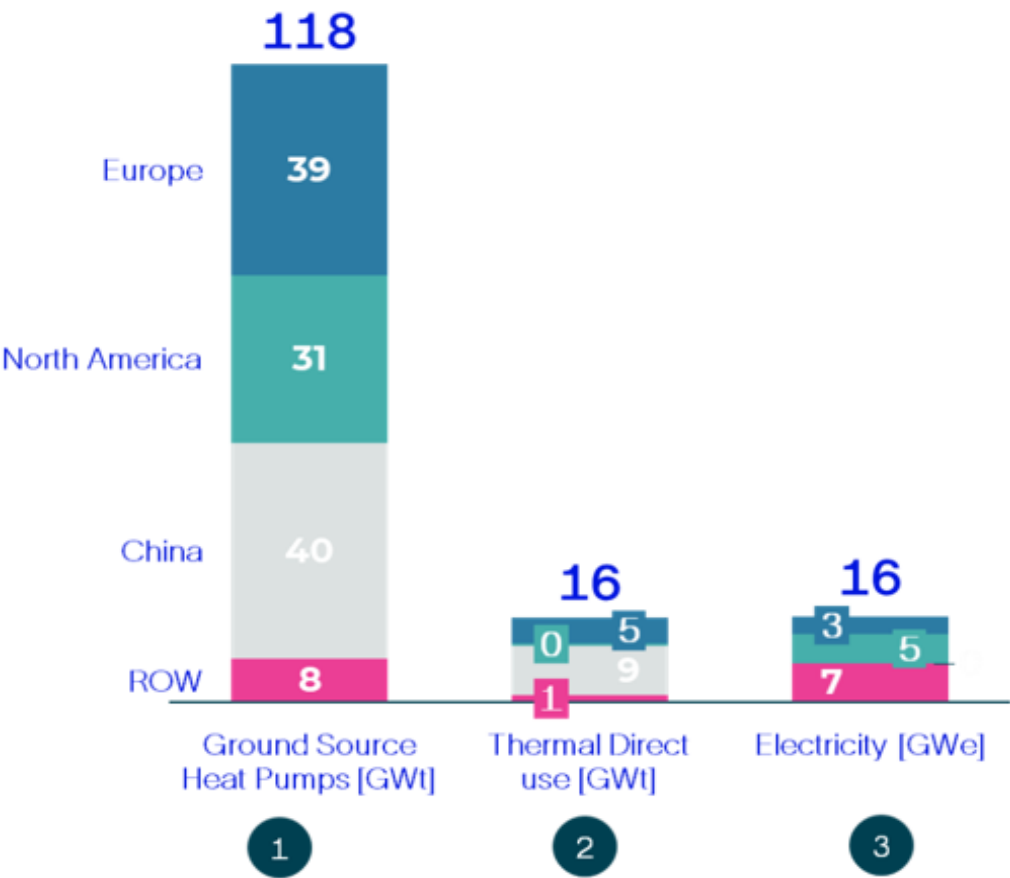
IEA. CC BY 4.0.



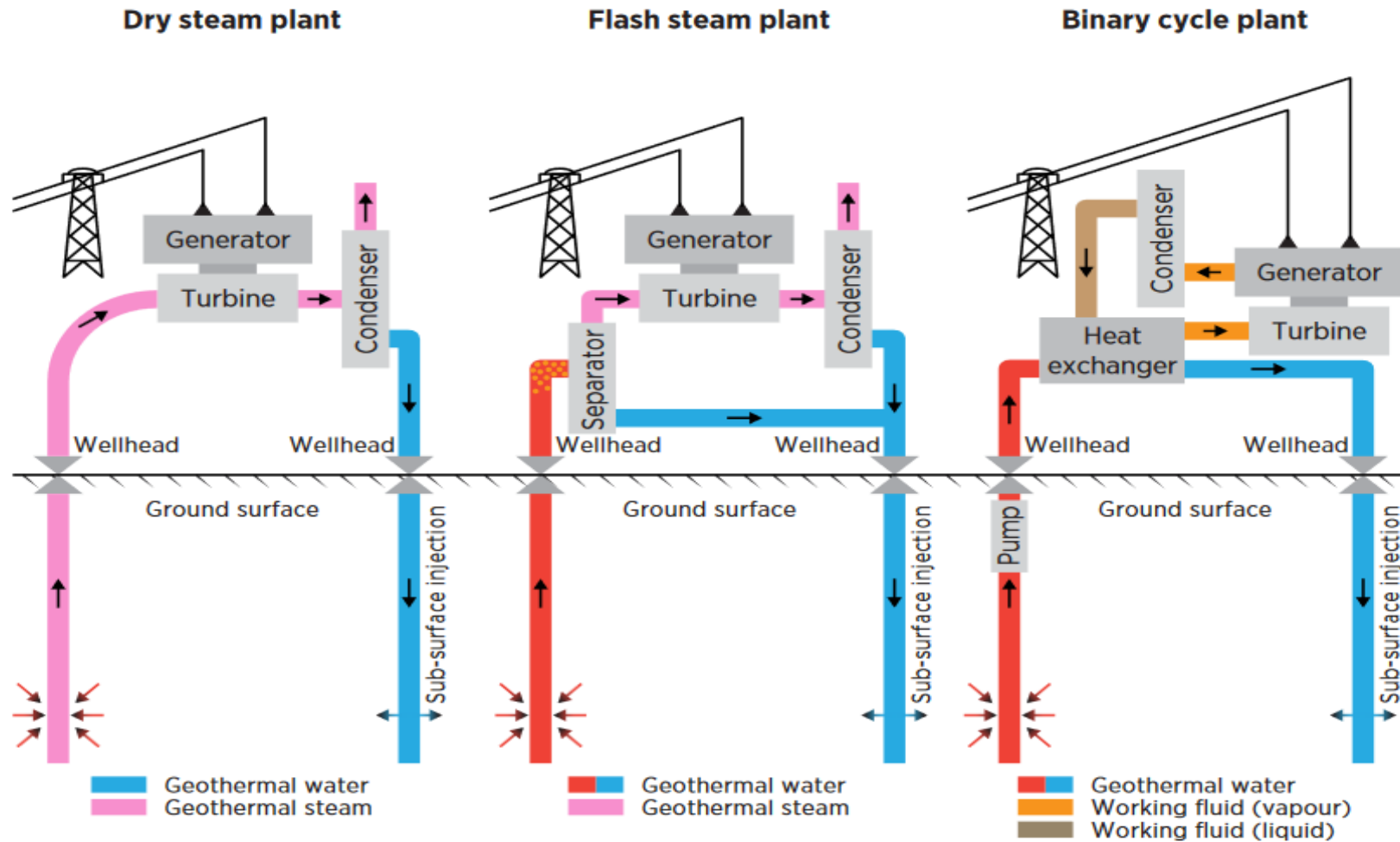
Geothermal Technologies



2022 Installed Capacity [GW]

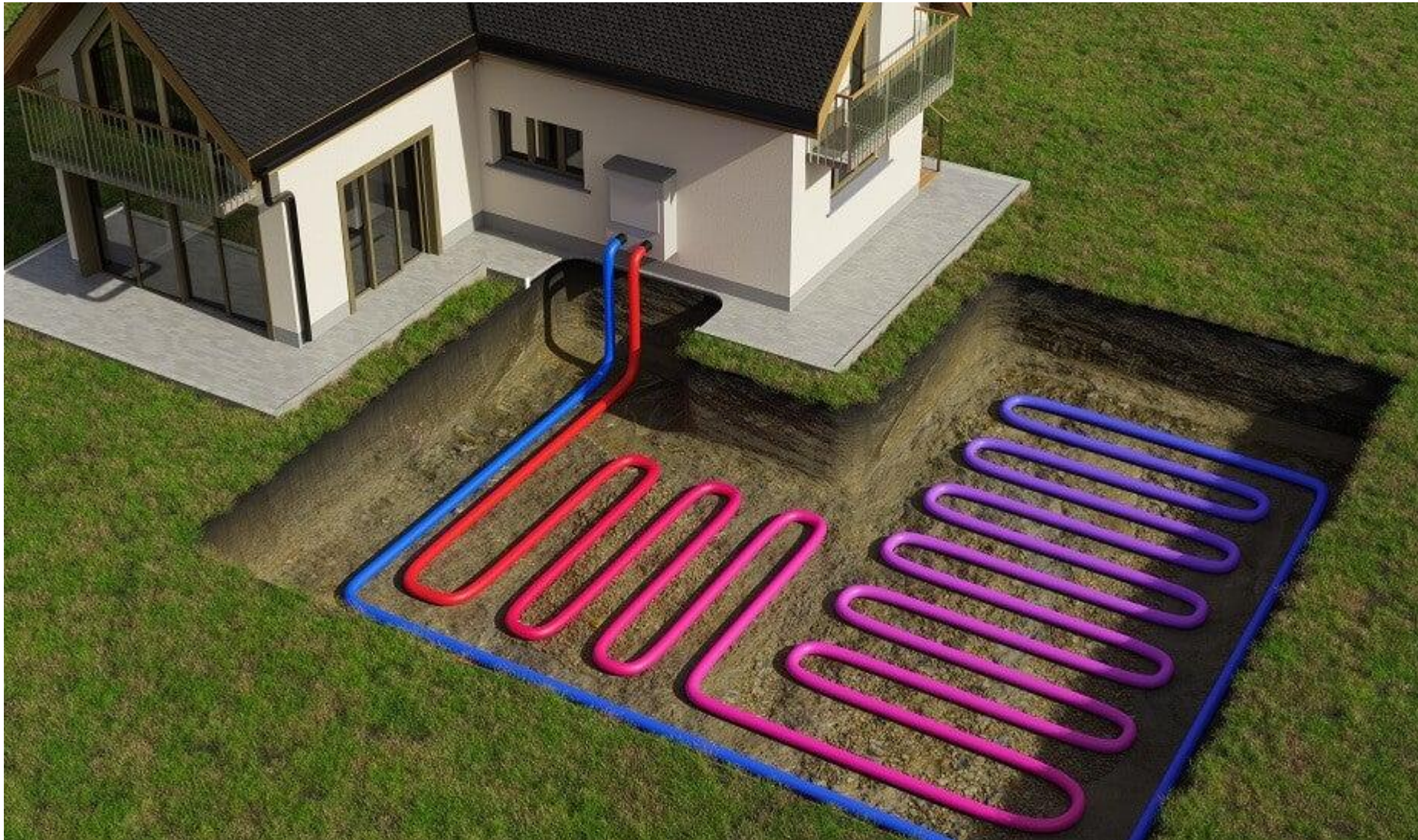


Geothermal Power Plant Technologies

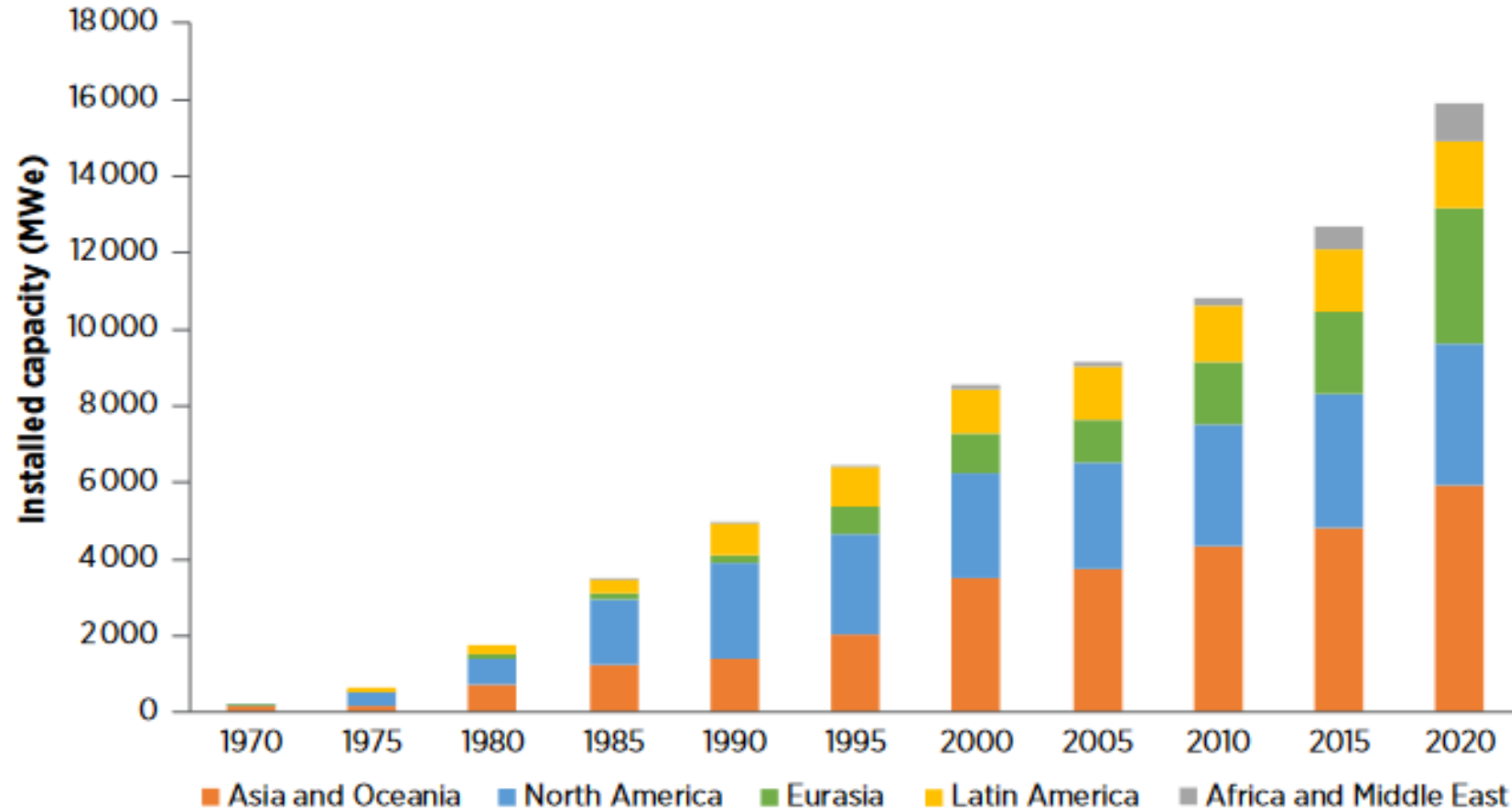


Based on: USGS (2003).

Example: Ground Source Heat Pump



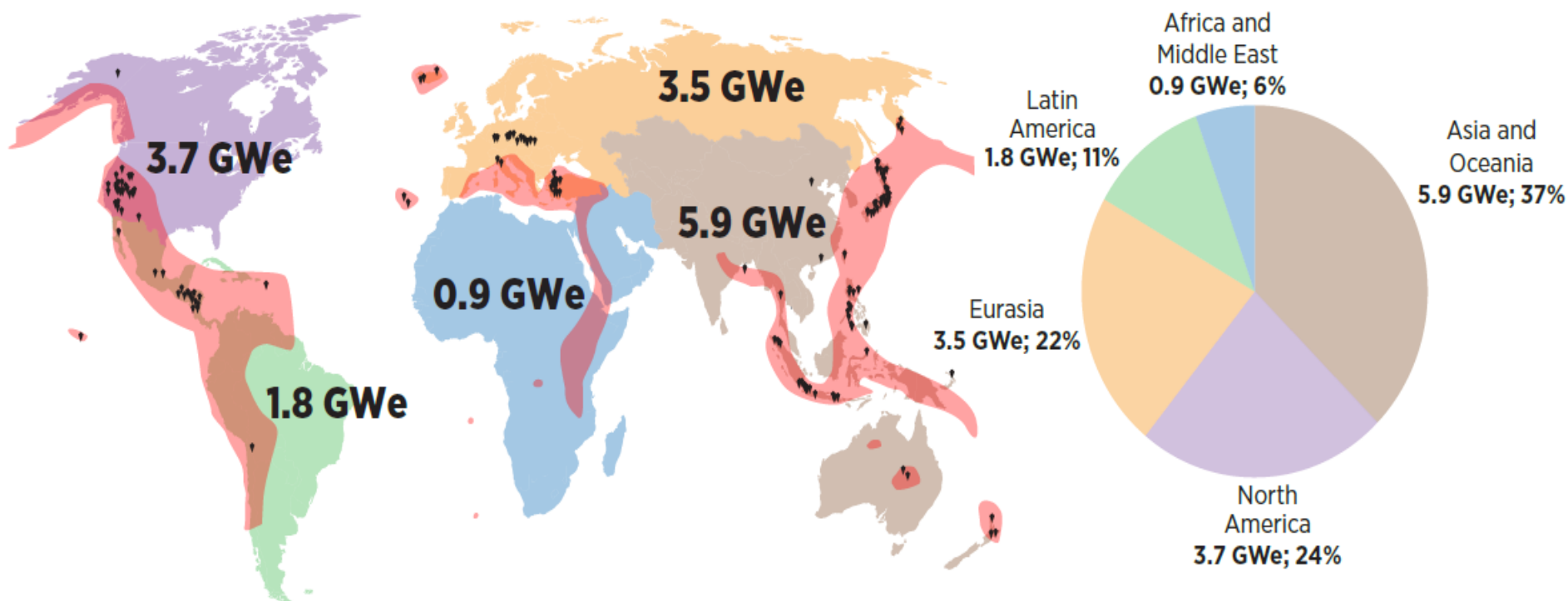
Growth of installed Geothermal Electricity Capacities



Source: ThinkGeoEnergy statistics, ThinkGeoEnergy (2022b), Hutterer (2021), Uihlein (2018), and Bertani (2015).



Installed Geothermal Electricity Capacities by Regions



Source: IRENA, 2022a; ThinkGeoEnergy, 2022 (b); Hutterer, 2021.

Note: The red zones on the map indicate high-temperature geothermal zones. The black symbols indicate geothermal electric plants, many of which are located in high-temperature zones. The geothermal regions used in this report were selected based only on the occurrence and development of geothermal resources, not on political or socio-economic considerations.

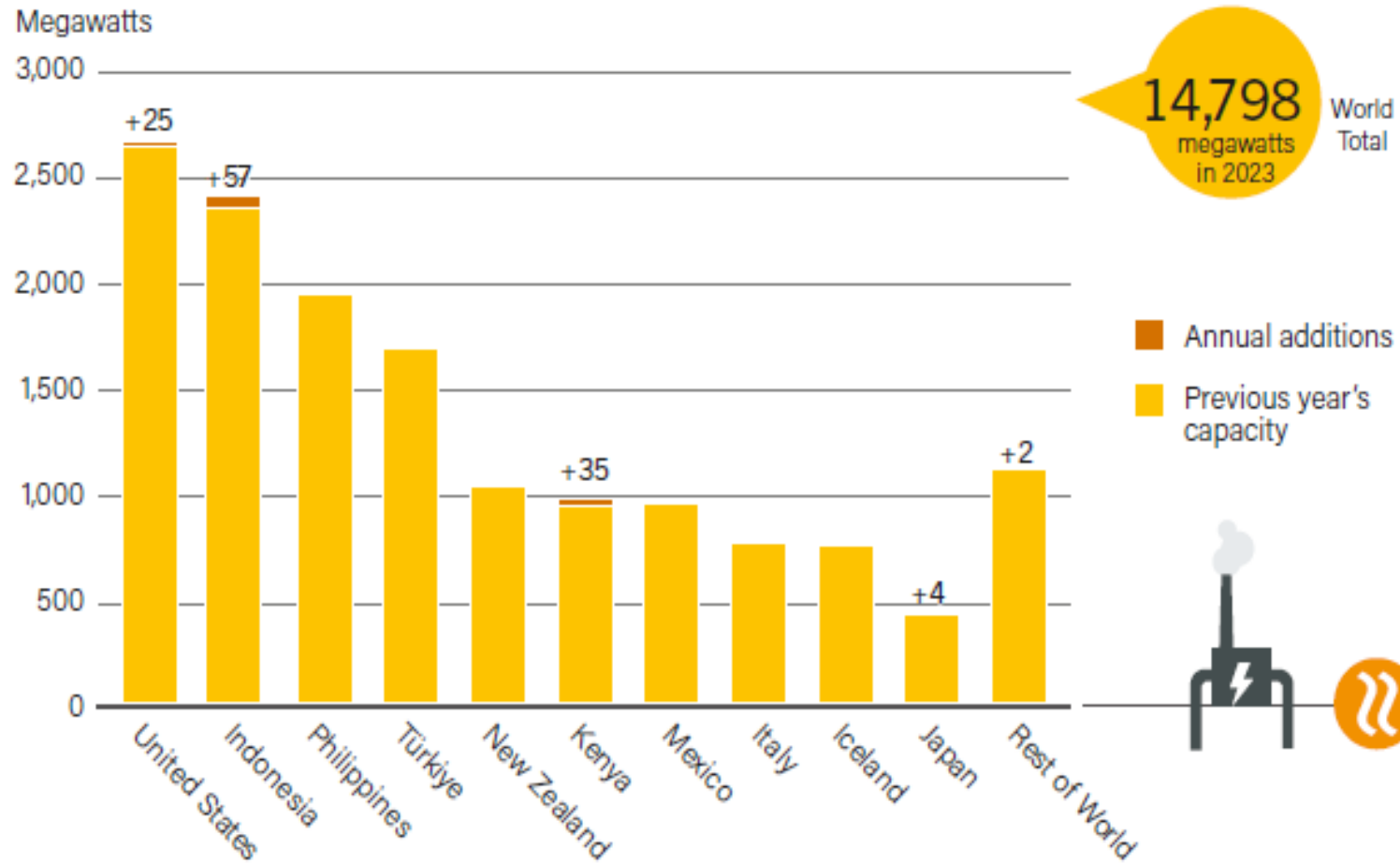
Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any endorsement or acceptance by IRENA.

Geothermal Electric plant in Japan

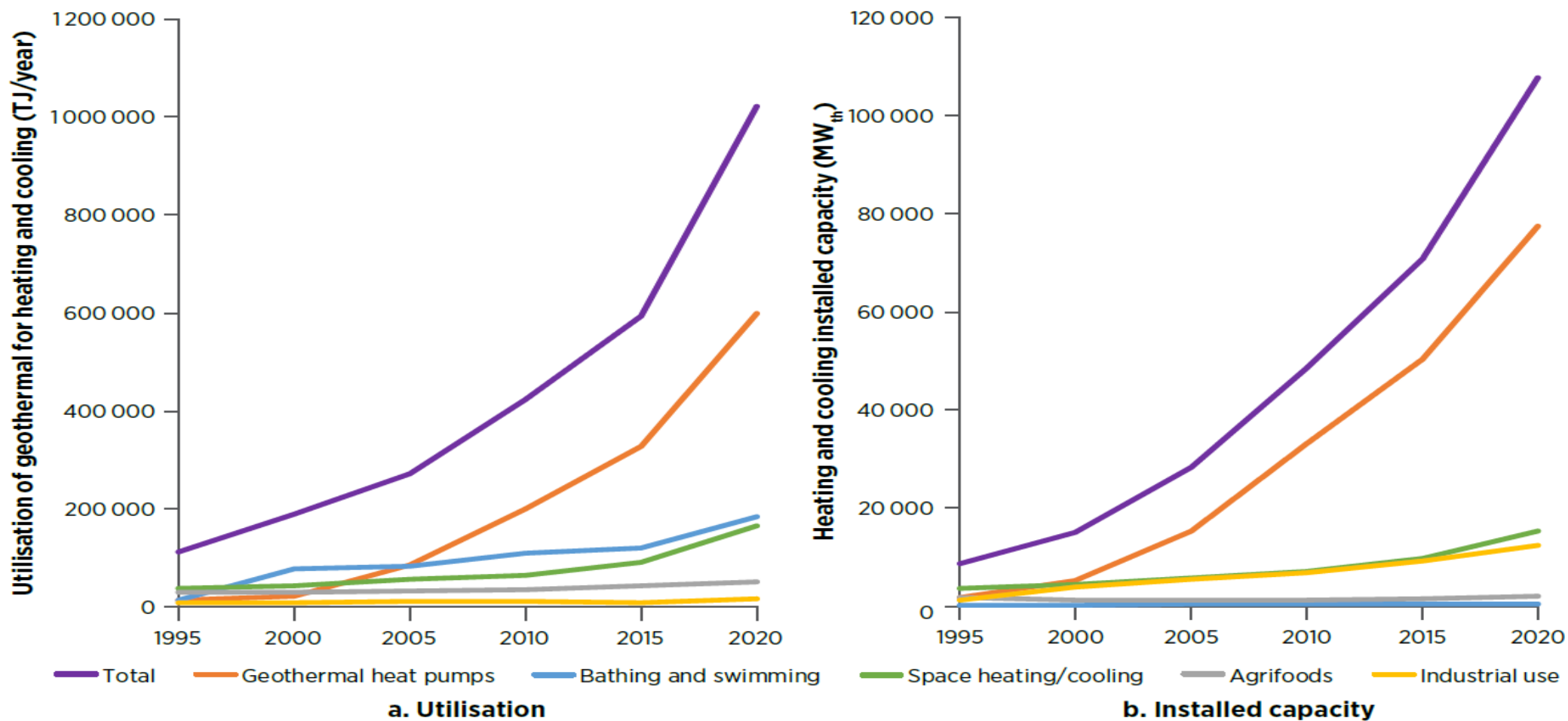


Source: IRENA 2023 Global Geothermal

Top 10 countries for Geothermal Capacity (MW) Year 2023



Geothermal Usage & Capacities by types (TJ & MW) Heating & Cooling

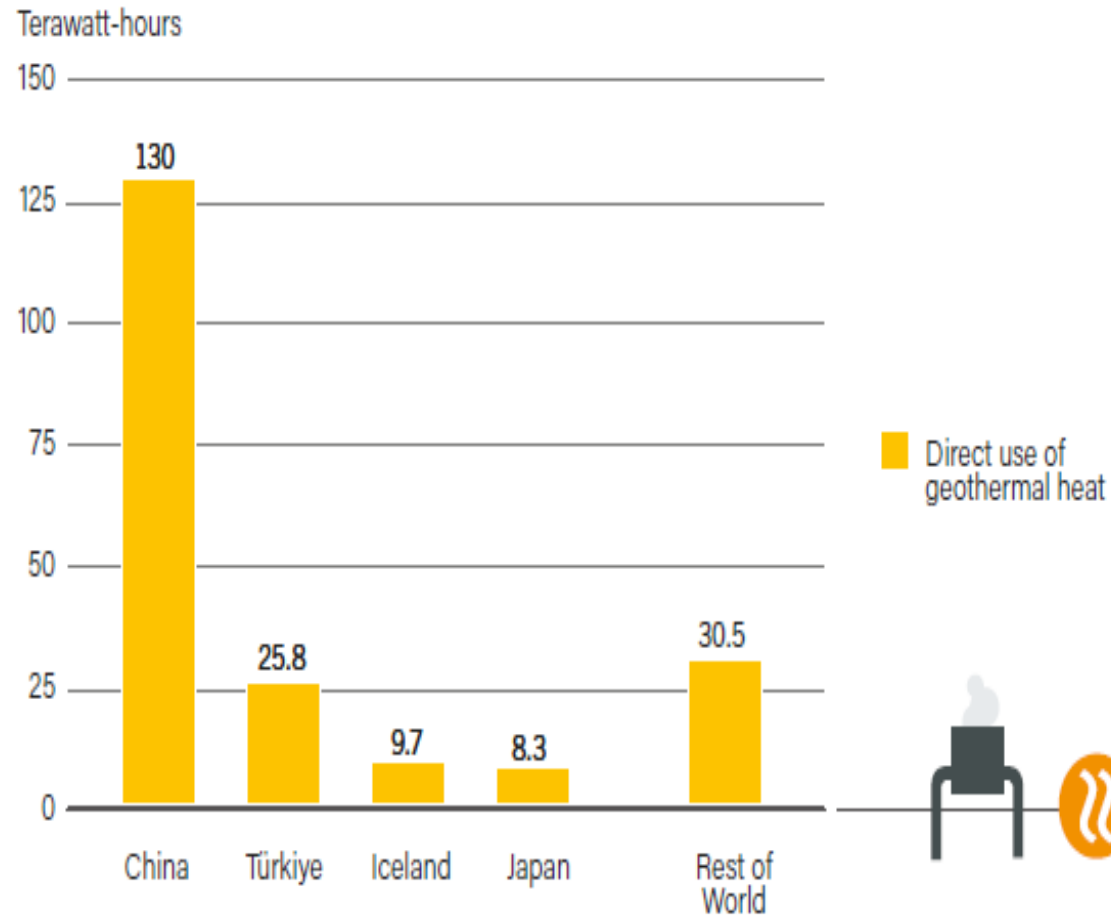


Source: Lund and Toth (2021).

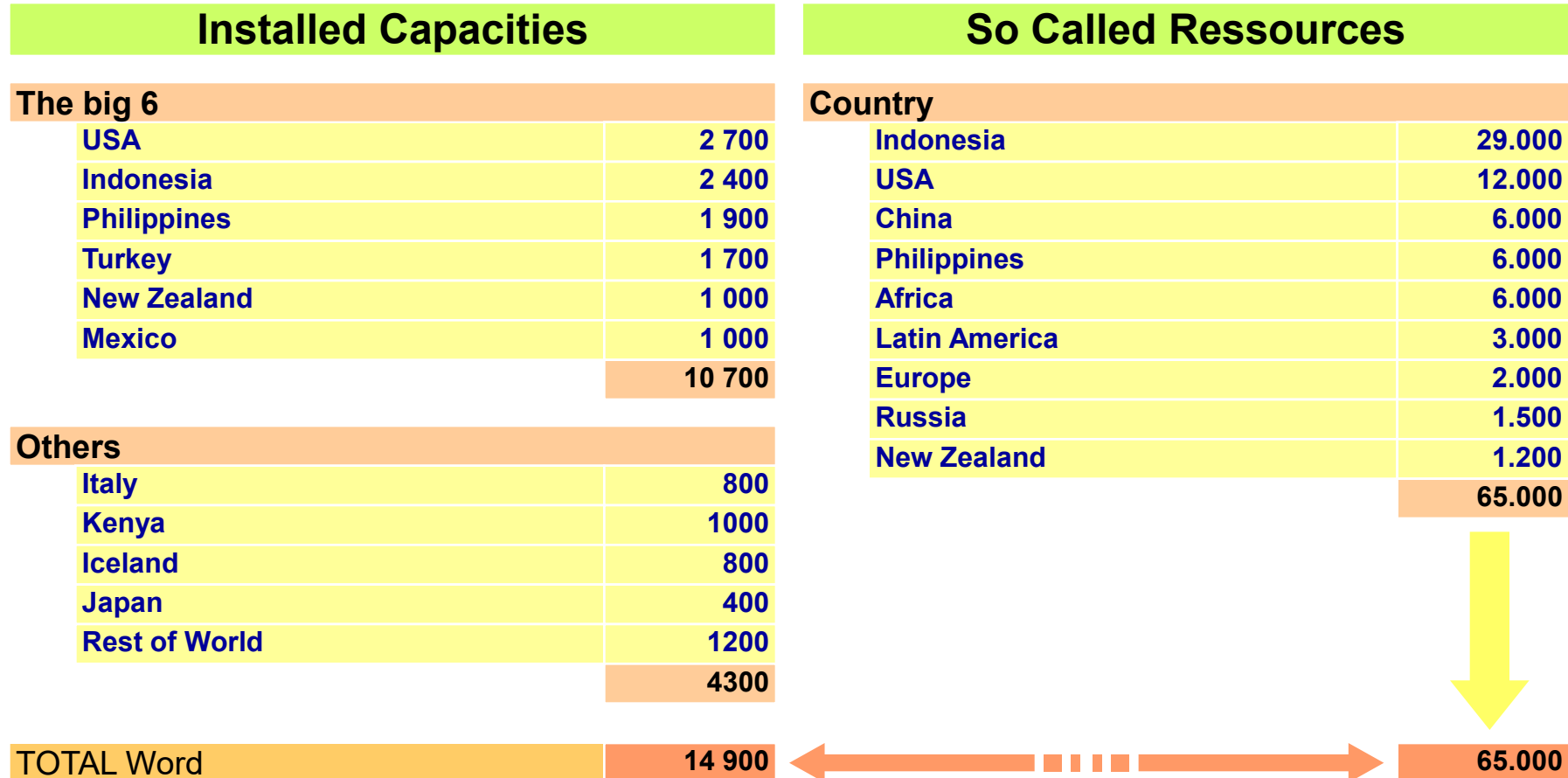
Source: IRENA 2023 Global Geothermal



Geothermal Direct Use by Countries (GW) Year 2023



World classical geothermal Installed Capacities & Resources 2023 (MW)



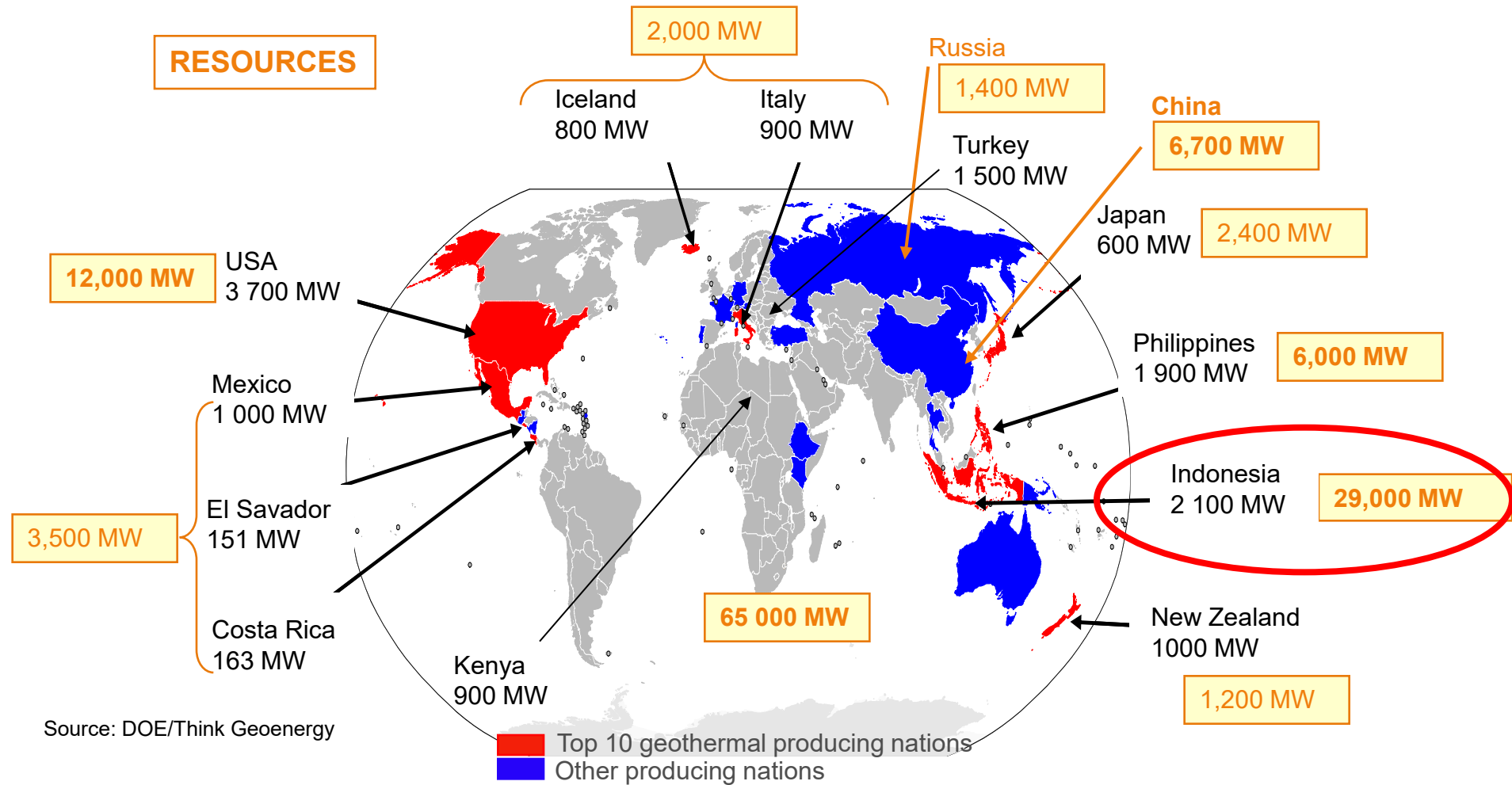
Source: Data from IRENA, ThinkGeoEnergy
REN21 2024 GSR/Rounded figures

Realities and dreams ...



World Outlook – Geothermal Producing Nations vs Resources

Reminder - Situation Year 2019



Indonesia has 40% earth's geothermal energy, but only 7% has been tapped.



Geothermal capacity and production in 2022/2023

- World total Geothermal Installed Capacities (**Electricity + Thermal Energy**) end 2023 # 150 GW
- World total Geothermal Production (**Electricity + Thermal Energy**) # 410 TWh (79% for buildings heating & cooling)
- World Installed **Power Capacity** end 2023 # 16 GW
- World Geothermal **Electricity Production** = 97 TWh in 2023 (0,3% of total Electricity Production)  # 330 TWh in 2030 to cope with the IEA NZE Scenario 2050??
- World Geothermal **Direct Use** Capacity end 2022 = 16 GW_{th}
- World Geothermal **Direct Use** Production = 128 TWh in 2020.
- World **Geothermal Heat Pumps (GHP)** Capacity end 2022 = 118 GW_{th}
- World **Geothermal Heat Pumps (GHP)** Production 2022 = 173 TWh
- Production cost # 50 to 150 \$/MWh, depending upon the characteristics of the sites.....



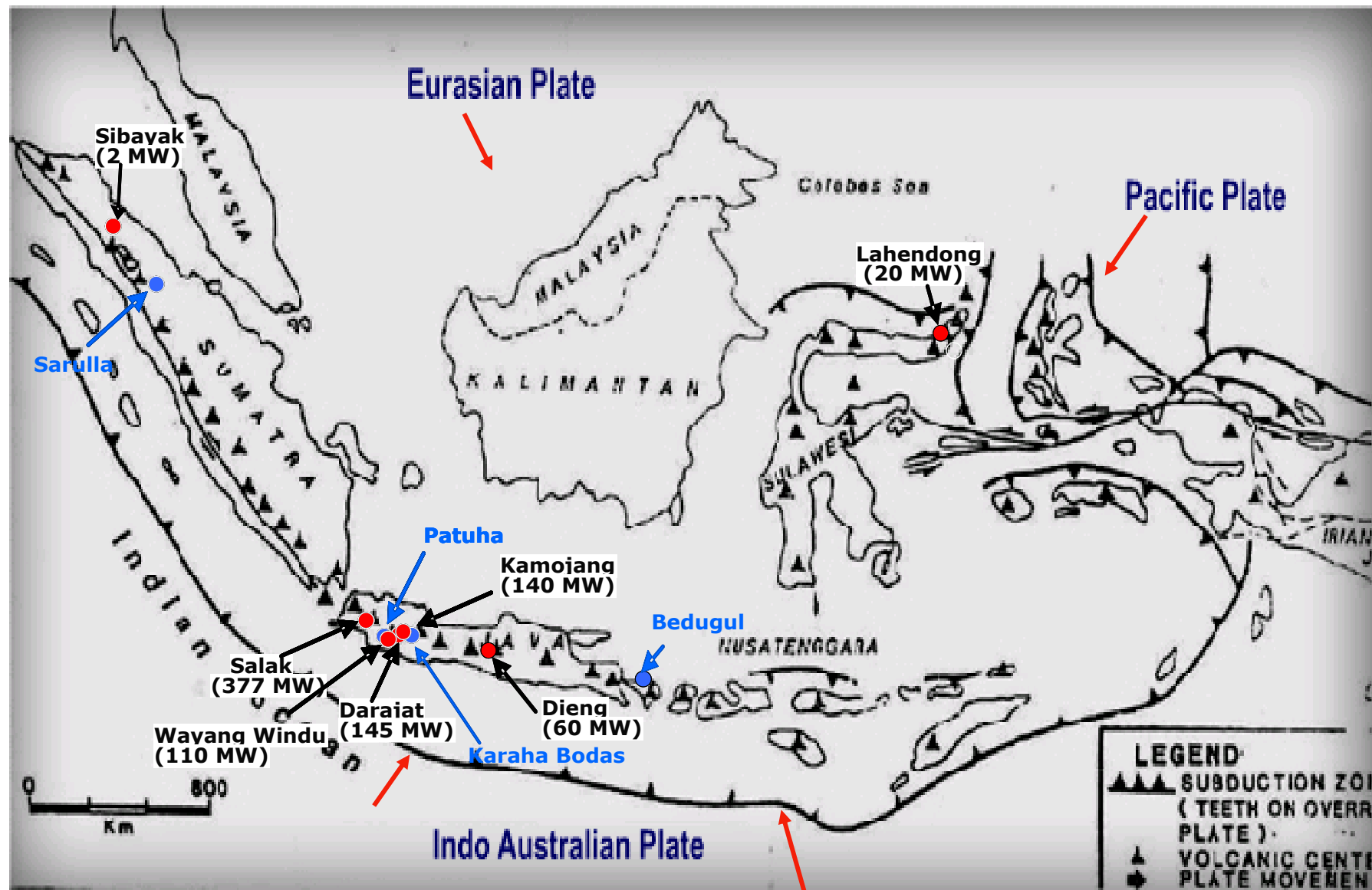
5-2

**What about
Indonesia ?**



Indonesia: N°1 for Potential Geothermal Resources N°2 for Geothermal Installed Capacity





Geothermal Regulatory and Legal in Indonesia

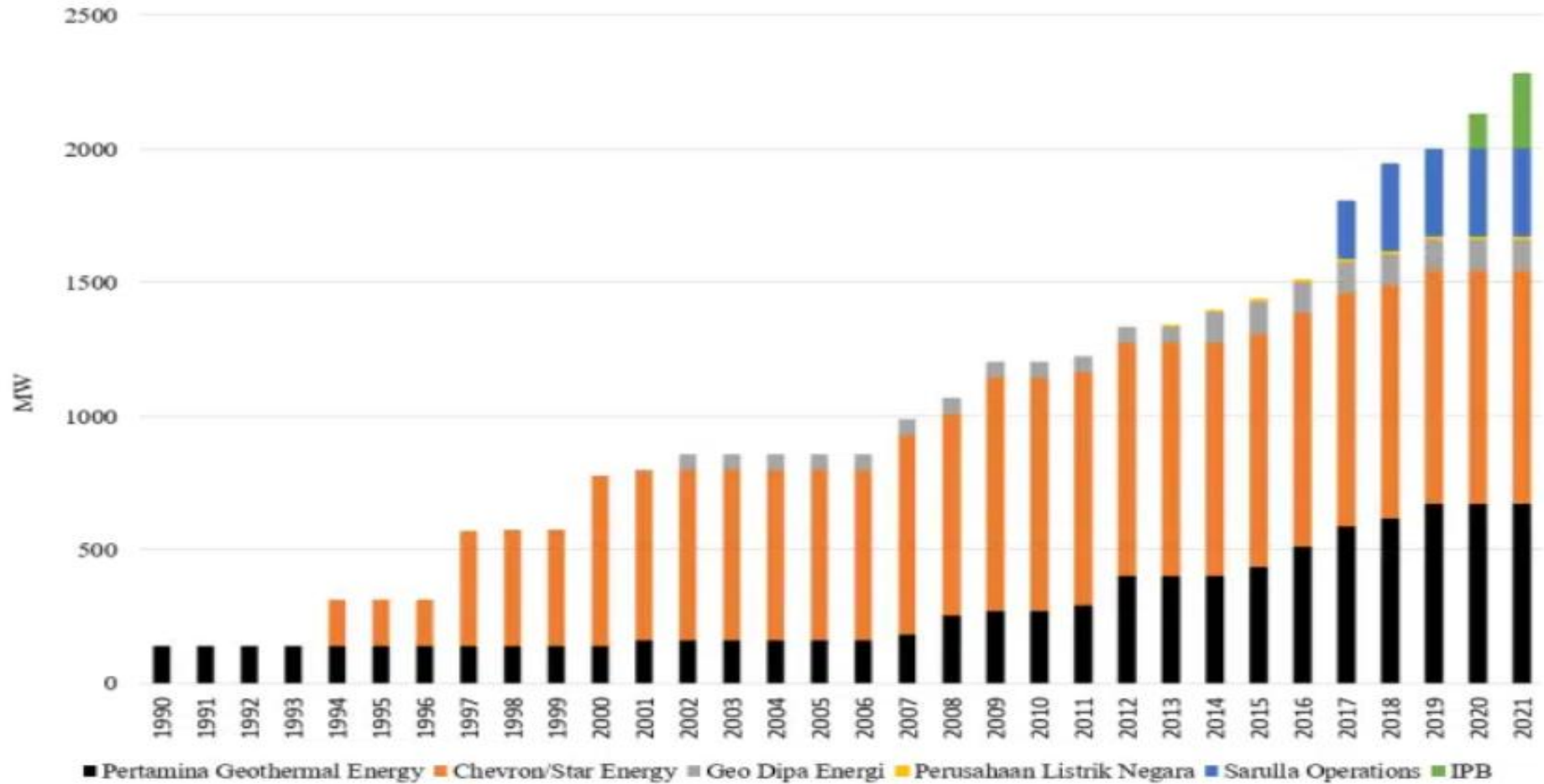
Old Law : PD45/91, PD49/91 & PD23/92

New Law: 27/2003 has been replaced by 21/2014 & Gov. Regul. n° 7 of 2017

Business Structure	- JOC with Pertamina - ESC with PLN	- IUP (Geothermal Business Permit) issued by Min.Regional Government - IUPTL (Electricity Supply Business Permit) by BAPEPTAL or government - Geothermal no longer mining operation
Government Split	34% of net income included all tax payment	Non tax levy and general tax law (not clarified)
Management	Under Pertamina (JOC) and PLN (ESC)	Under central or regional government
Project Execution	Integrated from exploration to electricity generation	- Survey and exploration by government - Exploitation by business entity
Energy Prices	USD	ID Rupiah. Prices defined in 3 area divisions with different benchmark prices.



Geothermal Development Indonesia 1990 - 2021



Source: Stanford

Source: Energy tracker Asia

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TPA Toolbox Energy Book 7 – Renewables

Geothermal Resources Indonesia

DISTRIBUTION OF GEOTHERMAL POSSIBLE RESERVES



Source: [Research Gate](#)

p.m. Installed Geothermal Plant 2006-2008

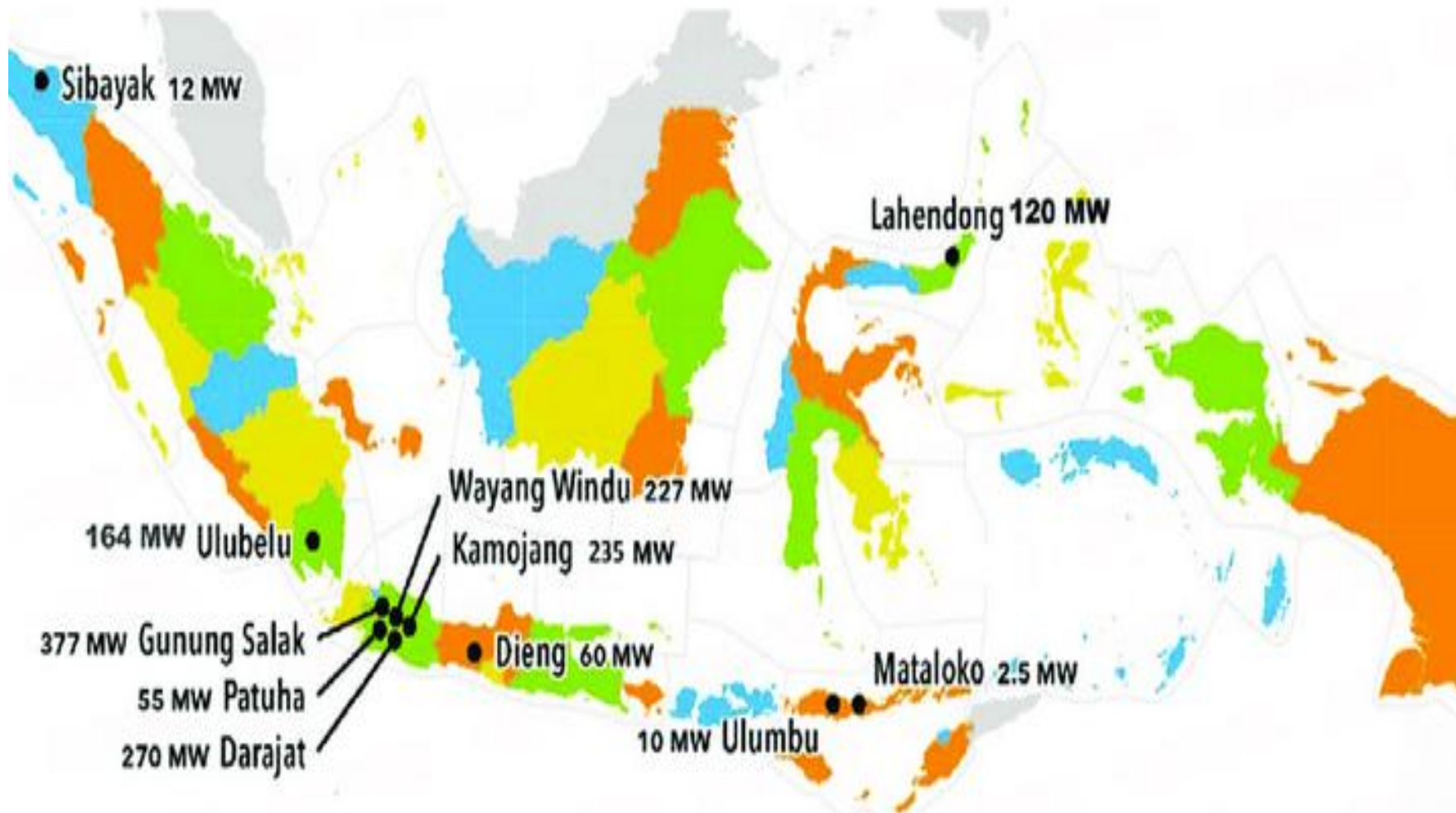
No.	Production Area	Location	Turbine capacity	Owner	Total Capacity (MW)		
					2006	2007	2008
1	Kamojang	Jabar	1 x 30 MW	PLN	140	140	200
			2 x 55 MW	PLN			
			1 x 60 MW	PLN			
2	Lahendong	Sulut	1 X 20 MW	PLN	20	40	60
			1 x 20 MW	PLN			
			1 x 20 MW	PLN			
3	Sibayak	Sumut	1 x 2 MW	Pertamina	2	12	12
			2 X 5 MW	Pertamina			
4	G. Salak	Jabar	3 x 60 MW	PLN	375	375	375
			3 x 65 MW	CGS			
5	Darajat	Jabar	1 x 55 MW	PLN	145	255	255
			1 x 90 MW	CGI			
			1 X 110 MW	CGI			
6	Wayang Windu	Jabar	1 x 110 MW	SE	110	110	110
7	Dieng	Jateng	1 x 60 MW	GDE	60	60	60
8	Bedugul	Bali	1 x 10 MW	Pertamina		10	10
Jumlah					852	1002	1082

Source: MEMR, 2007



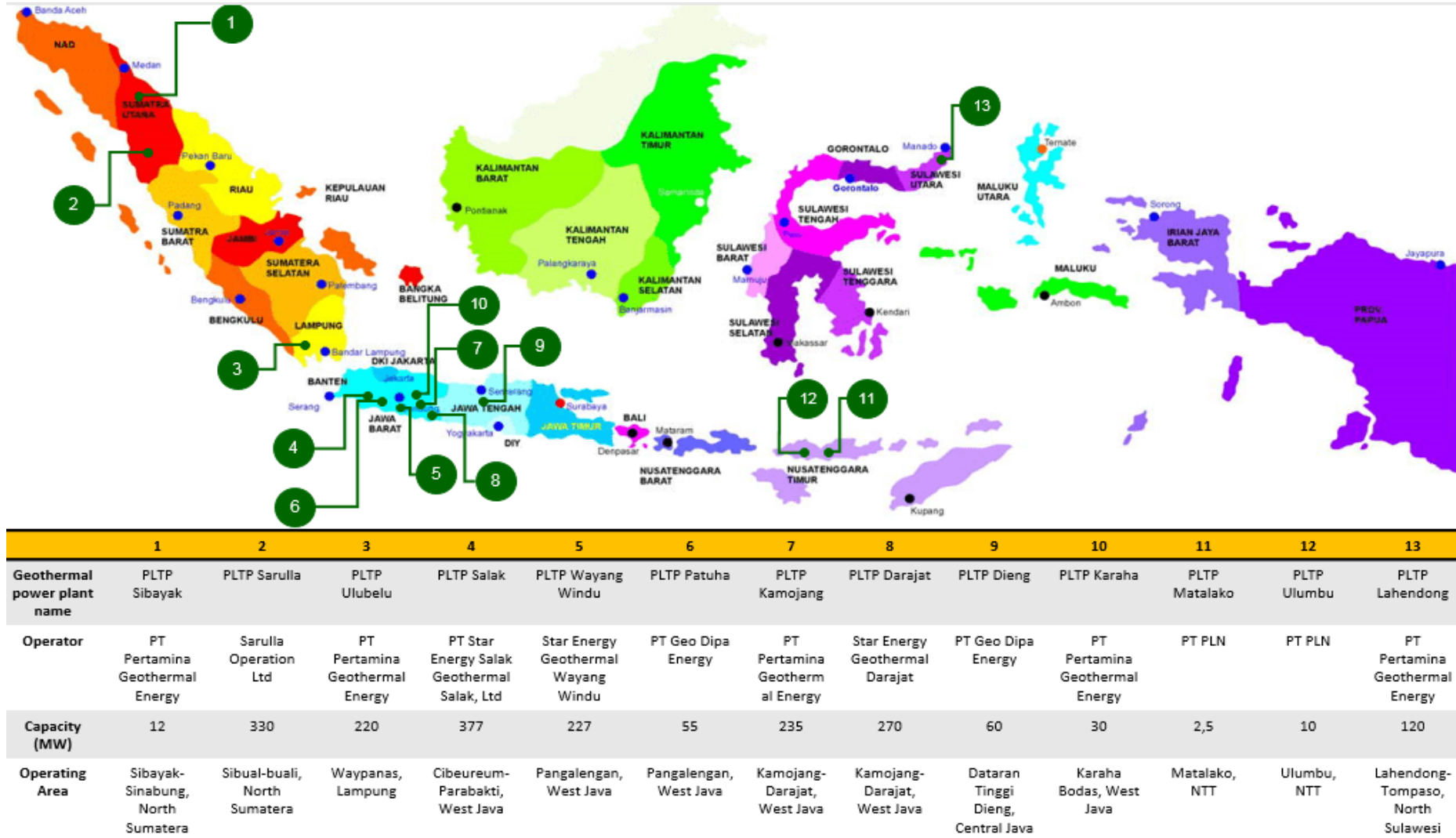
Geothermal in Indonesia – Situation 2017

New projects are under construction



Geothermal in Indonesia – Situation 2018

New projects are under construction



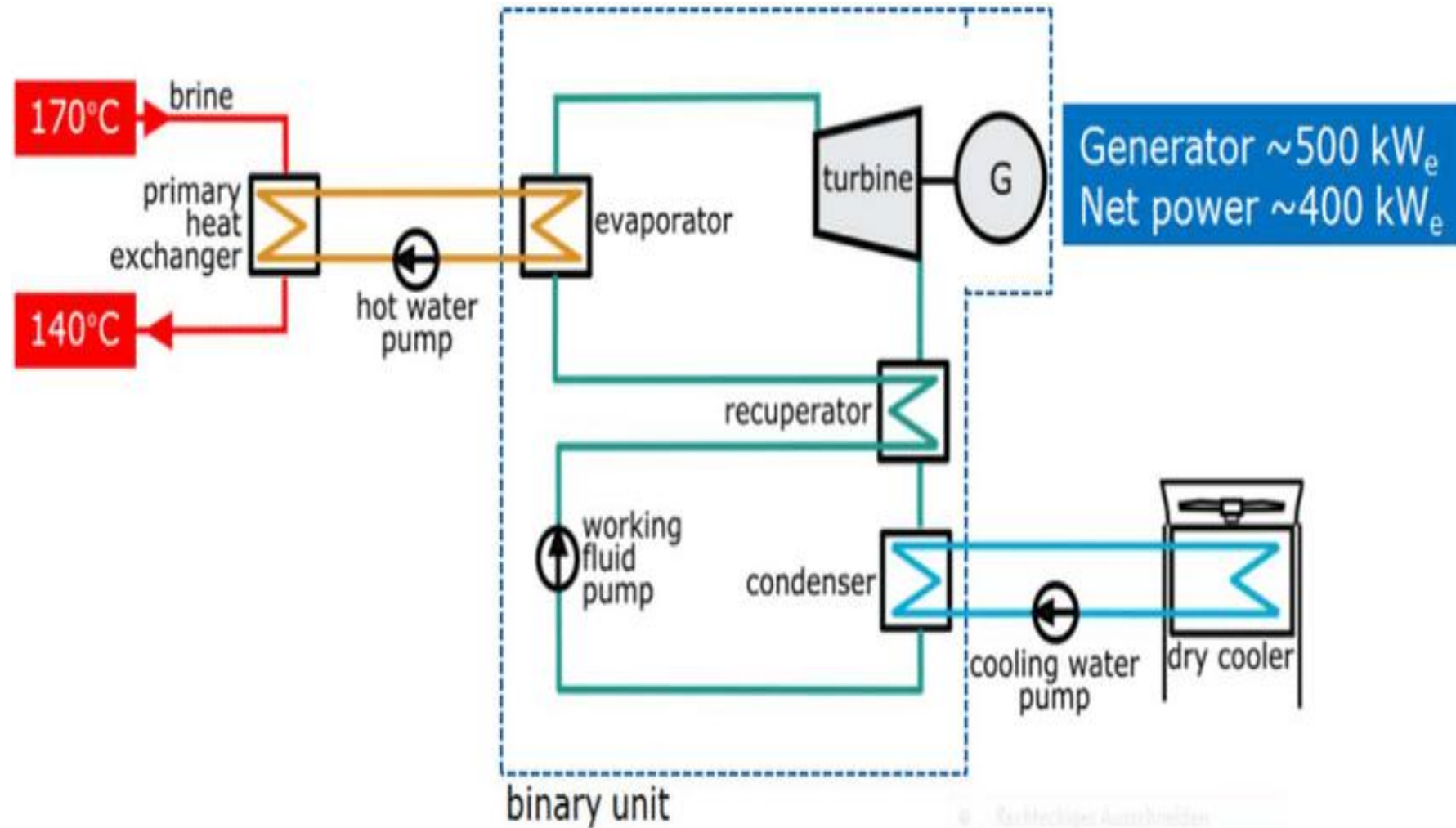
Geothermal in Indonesia – Situation 2018

New projects are under construction

Existing Plants	Location	Capacity 2017 (MW)	Capacity 2018 (MW)
Gunung Salak	West Java	377	377
Wayang Windu	West Java	227	227
Darajat	West Java	270	270
Kamojang	West Java	235	235
Patuha	West Java	55	55
Dieng	Central Java	60	60
Ulubelu	Lampung	165	220
Sibayak	North Sumatra	12	12
Lahendong	North Sulawesi	120	120
Ulumbu	NTT	10	10
Mataloko	NTT	3	3
Sarulla	North Sumatra		330
Karaha	West Java		30
Total		# 1500	# 1900



Schematic Diagram Binary Power Plant Lahendong





Marine Energy



BOOK 7 - TABLE OF CONTENTS

1. Global Remarks on Renewable Energy Sources

- Renewables in the Energy Mix –Trends/Perspectives – Investments – Potential/Diffusion/Network – Subsidies – Intermittency – Competitiveness – France PPE – Total Positioning – Criticality of Mineral Matters Resources – Dismantelment/End Life Equipment Recycling

2. Wind Energy

3. Solar Energy

4. Biomass Energy

5. Geothermal Energy

6. Marine Energy



6-1

General features



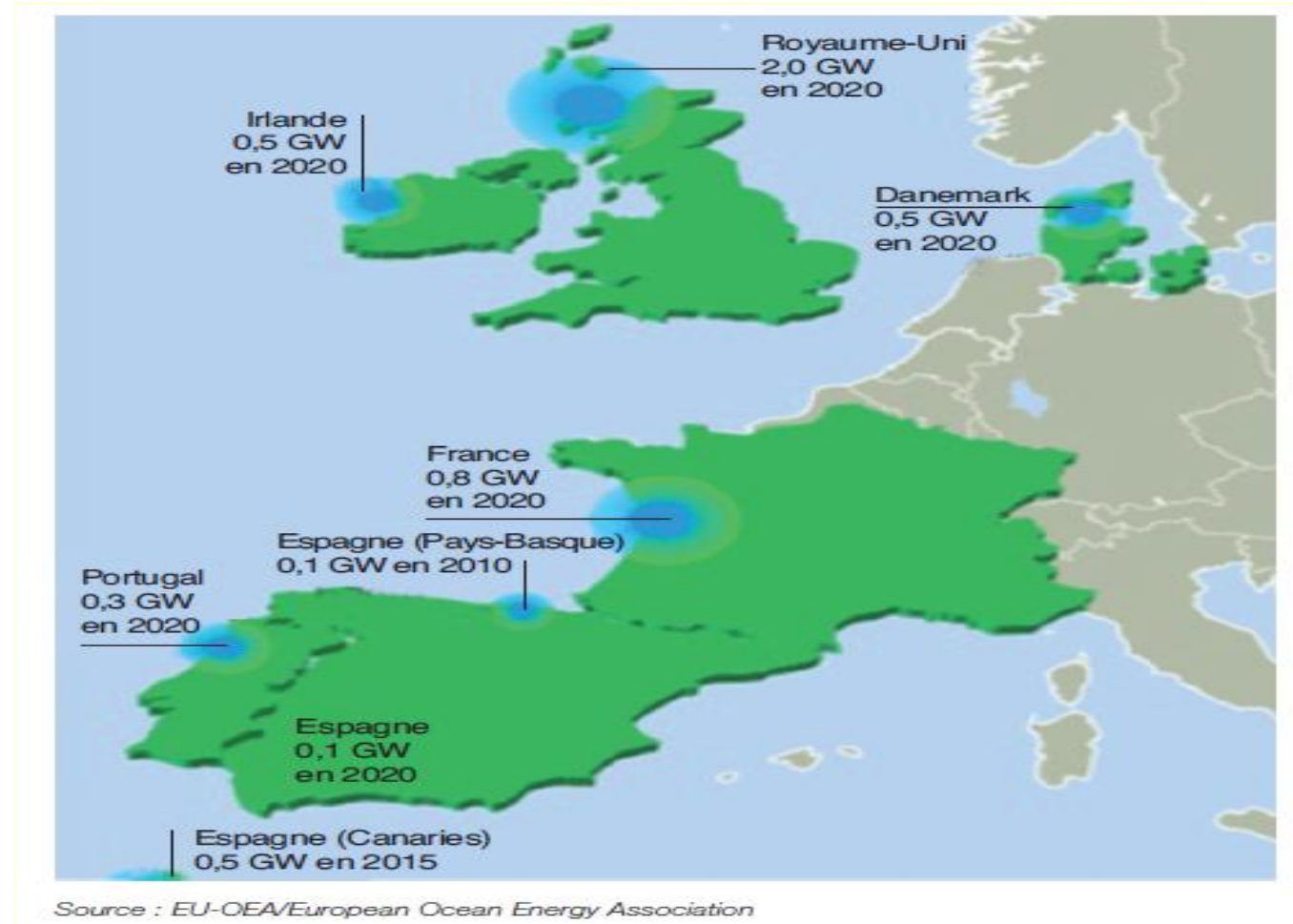
Marine Energy

**# 494 MW Installed Capacity worldwide
in 2024
919 GWh Electricity generated
In 2023**

Source: IRENA Renewable Energy Statistics 2025



Marine Energy projects in Europe (excluding wind offshore) – **Reminder: Objectives 2020**

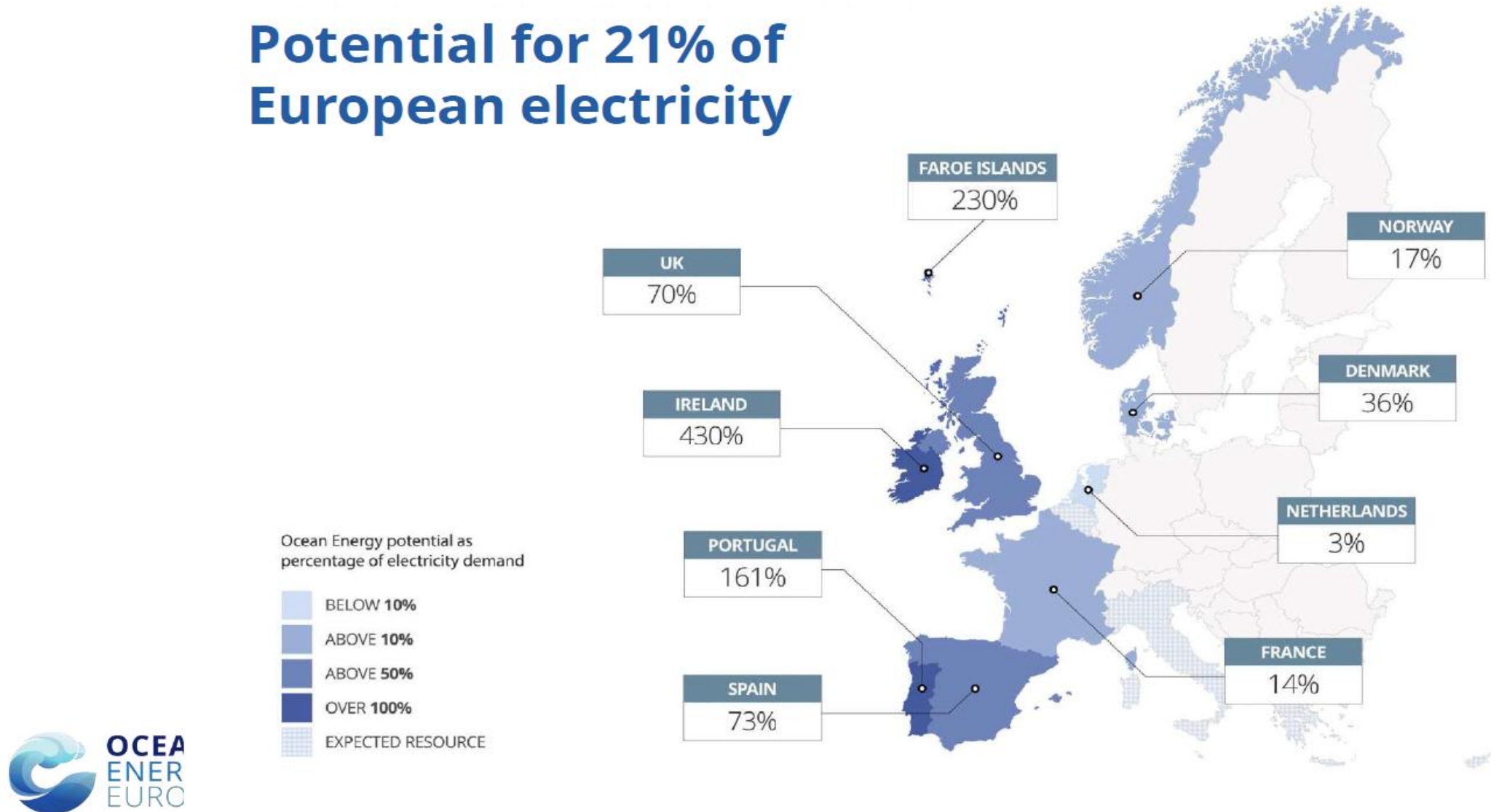


Source: IFPEN

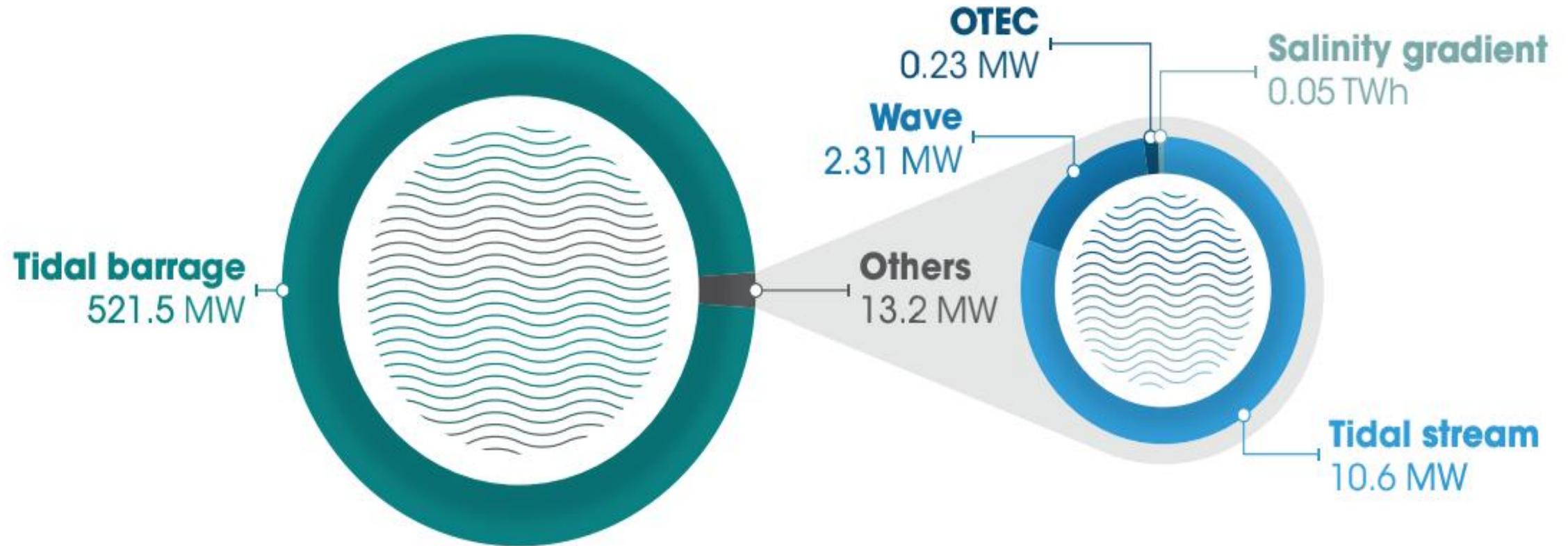


Marine Energy projects in Europe – Future deployment locations

Potential for 21% of European electricity



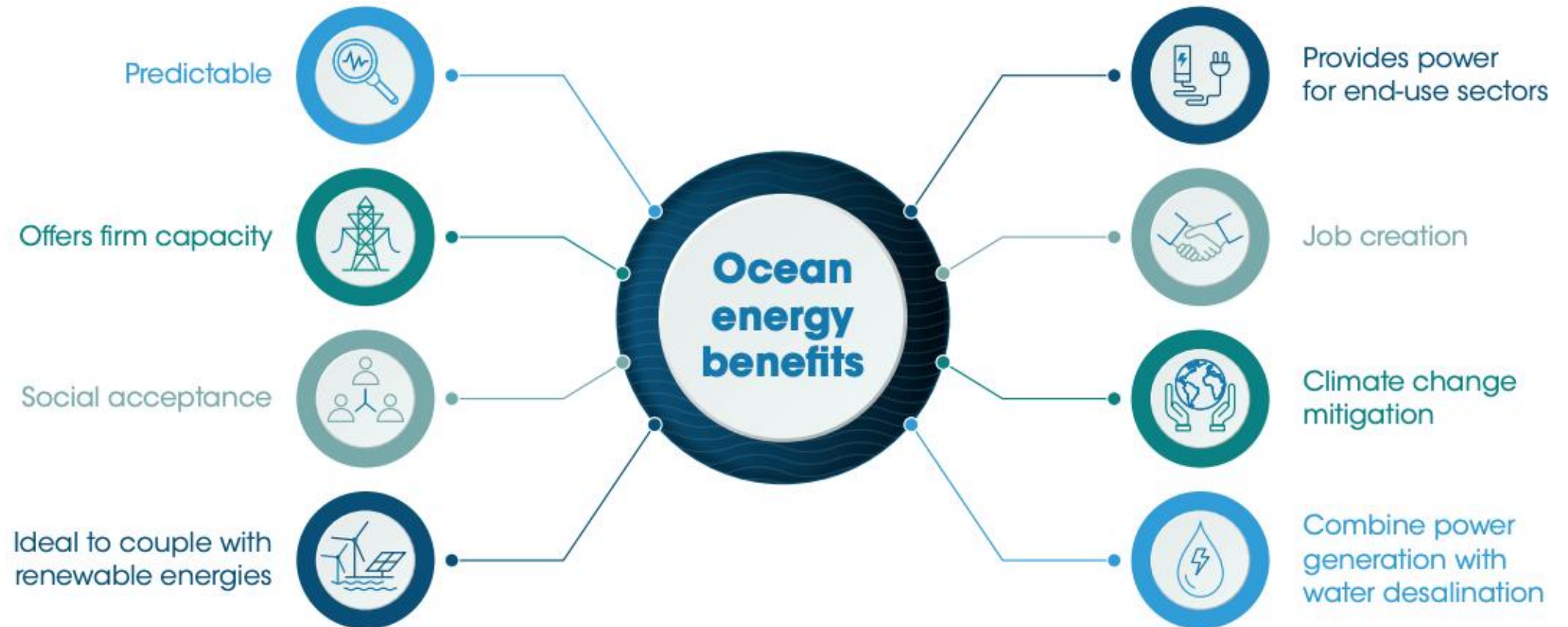
Reminder: Current Marine Energy deployment



Source: IRENA (2020a).



Reminder: Benefits of Marine Energy technologies



Source: IRENA (2020a).



Marine Energy projects perspectives by Ocean Energy Europe

New generation of farms kick-starts large-scale deployment

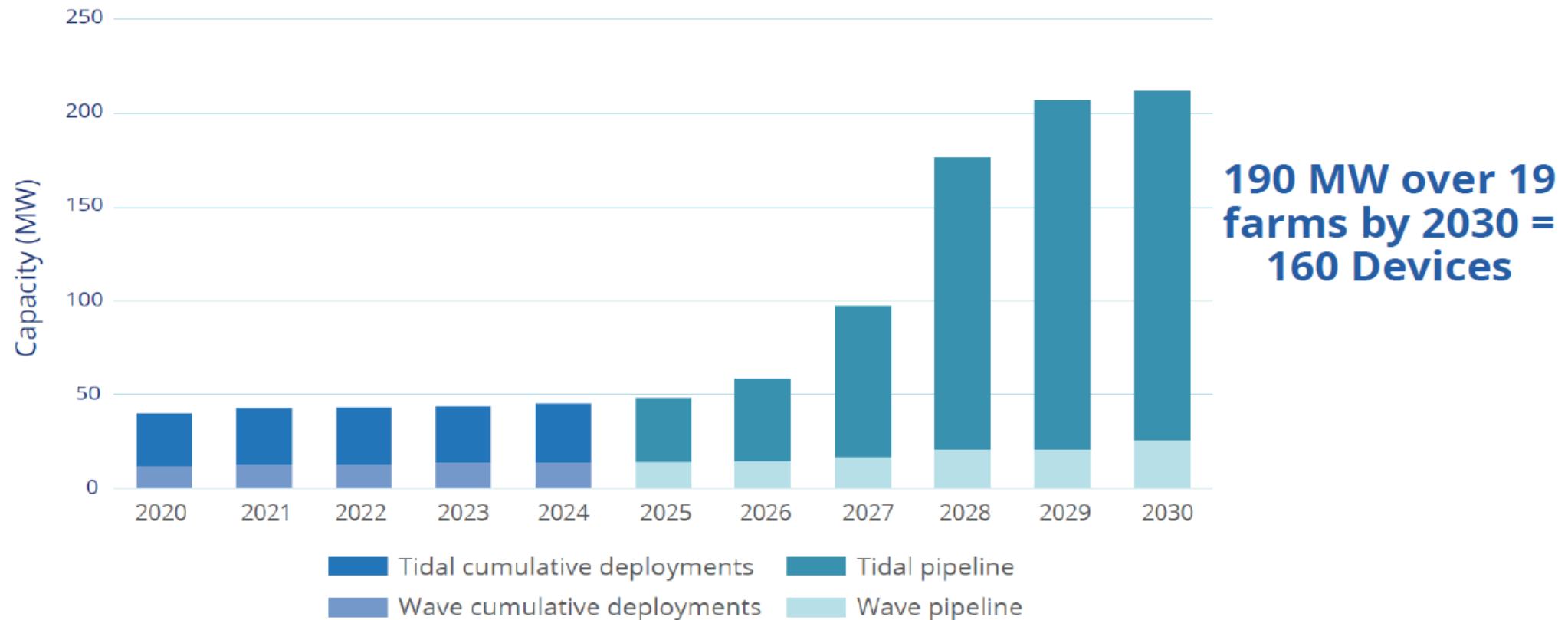
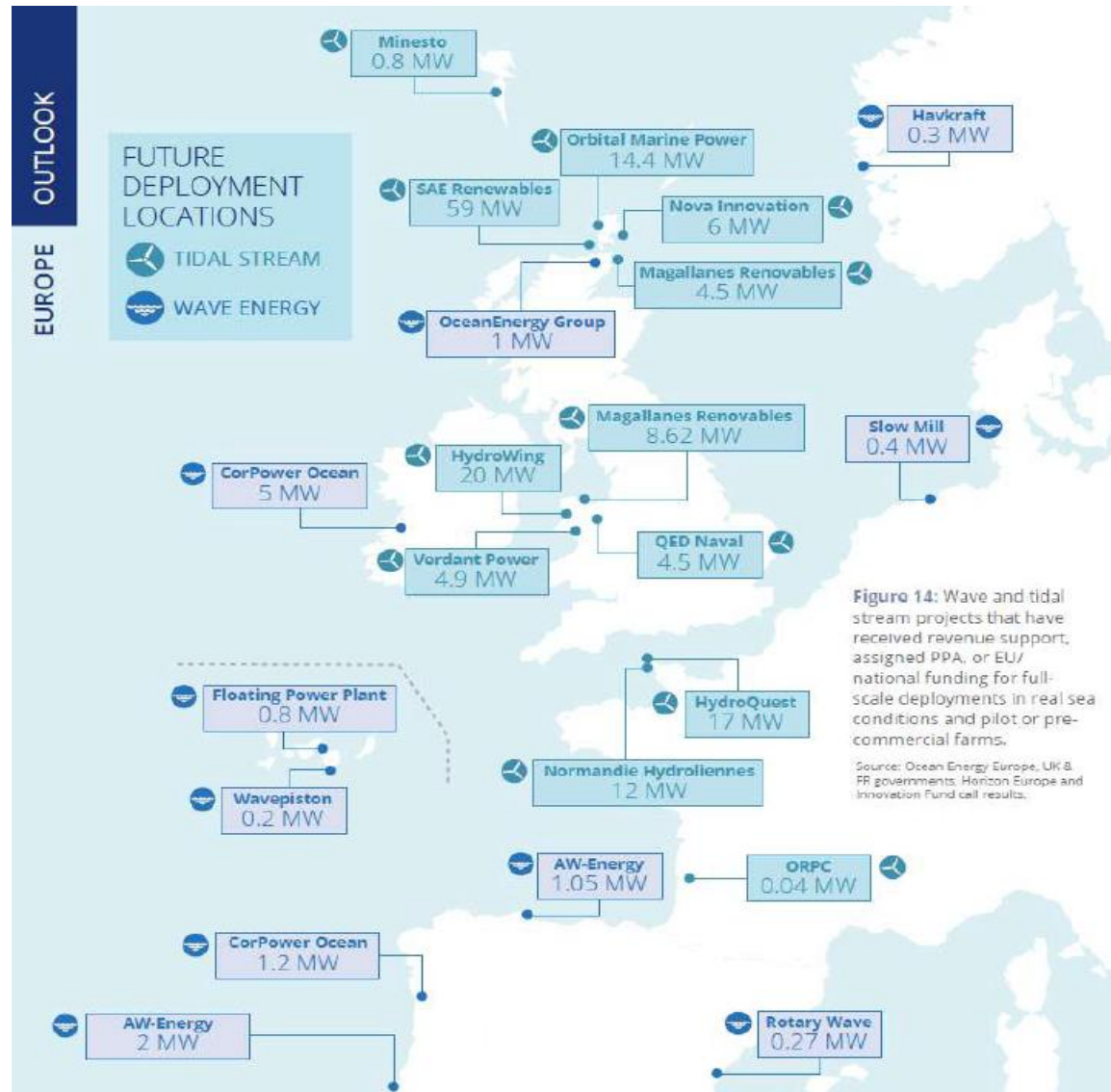


Figure 1: Ocean energy cumulative deployments and pipeline

Source: Ocean Energy Europe, UK & FR governments, Horizon Europe and Innovation Fund call results.



Marine Energy projects perspectives by Ocean Energy Europe



19 Farms
160 Devices
Project Pipeline
→ 2030



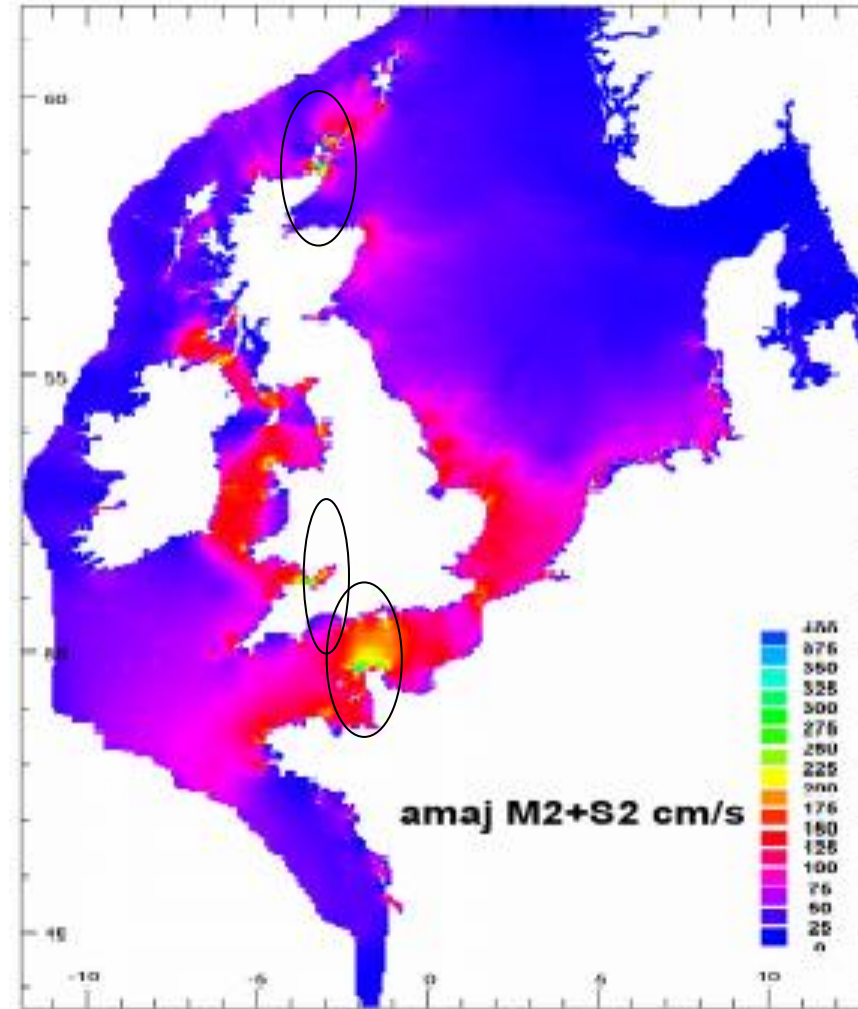
6-2

UK and Marine Energy (a key example)

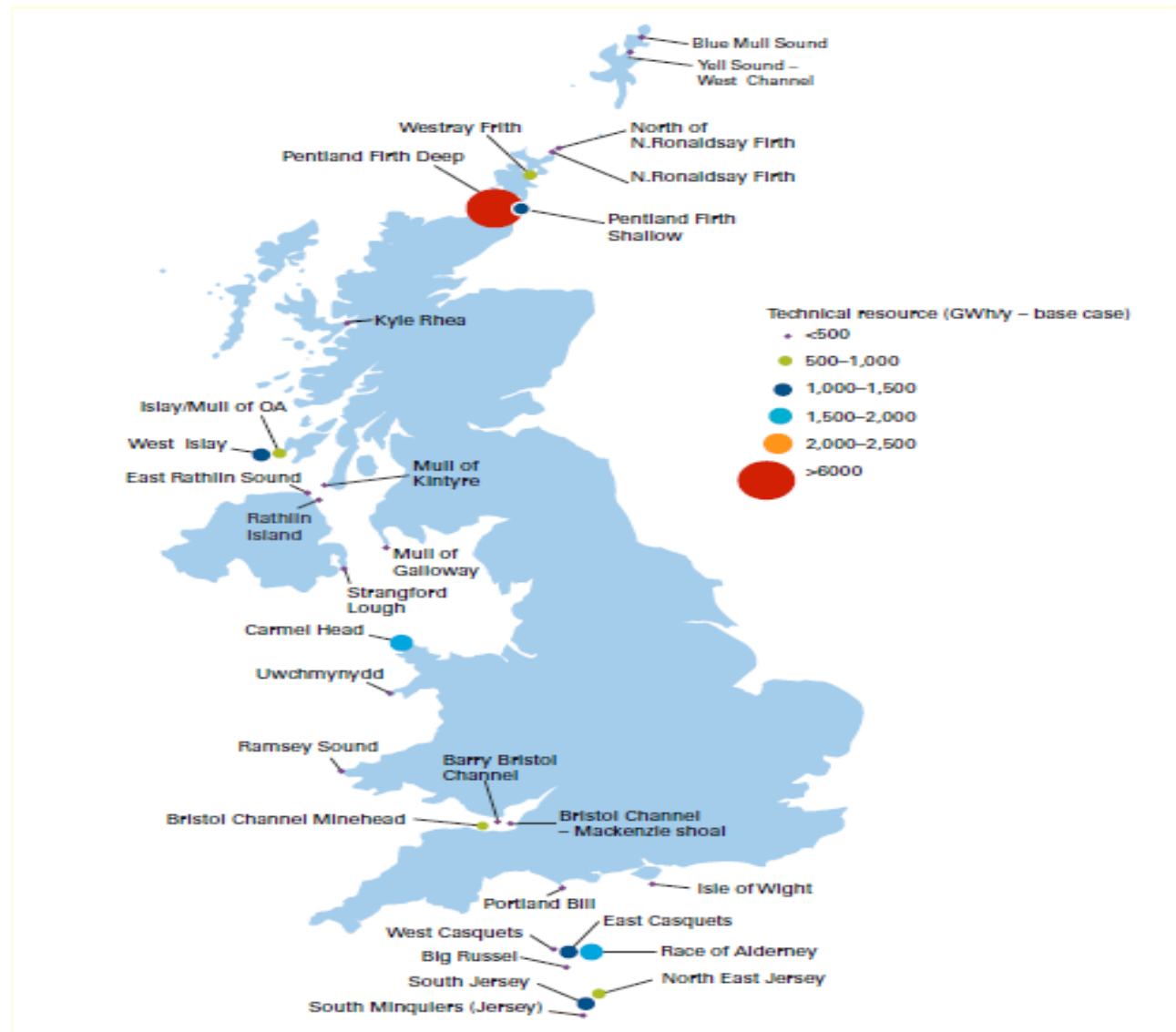


Hydrocinetic Energy (or tidal Energy) (or sea-currents Energy)

- ◆ Orders of magnitude to remember :
- ◆ Much higher « energy density » than Wind :
- ◆ in Kw/m²
 - Wind at 13 m/sec = 1.3 Kw/m²
 - sea current at 2 m/sec = 4 Kw/m²
- ◆ Because of retroaction effects, practical limits are :
 - 6 Mw/Km² for offshore windmills
 - 10 Mw/Km² for under water-mills

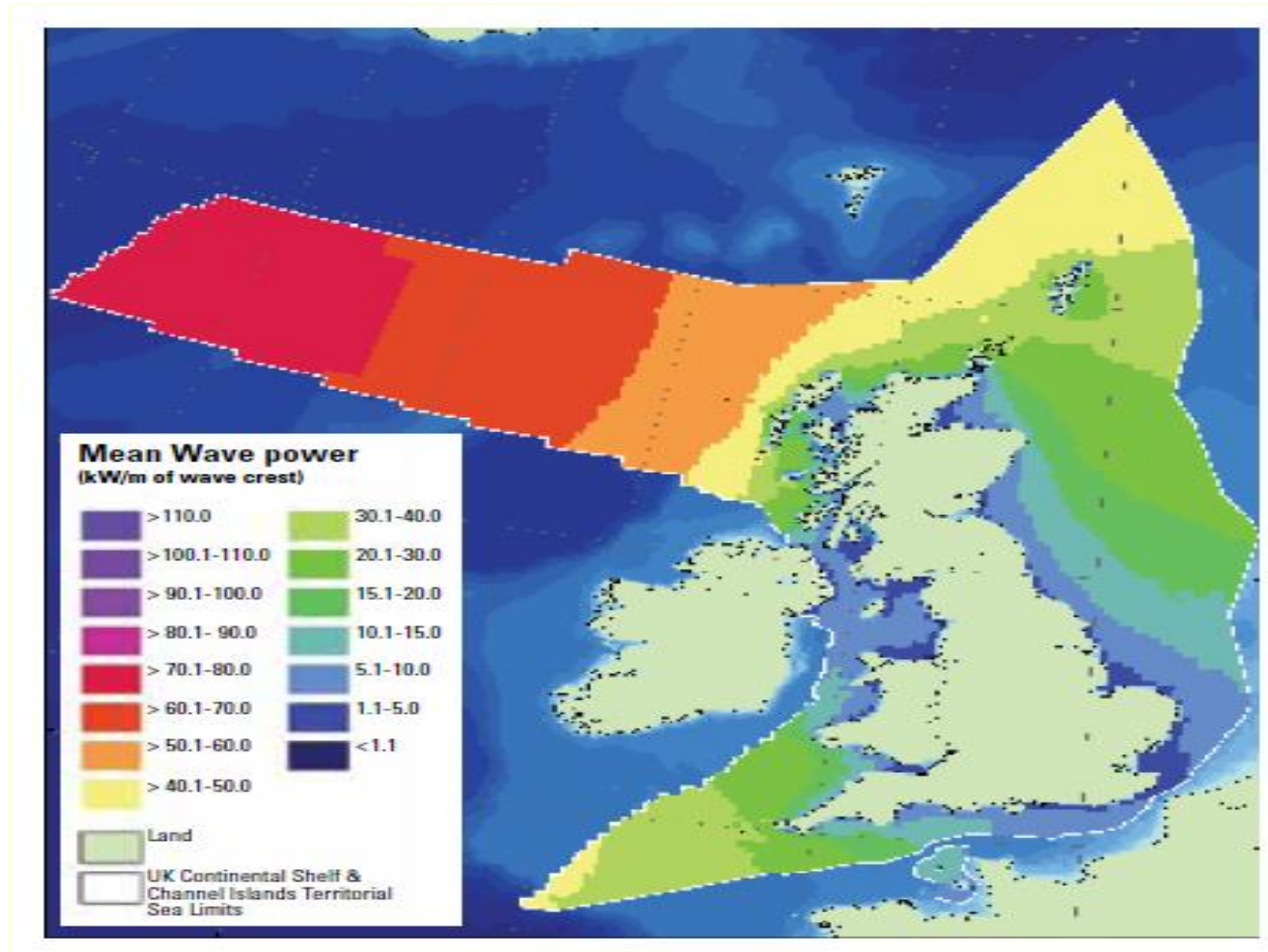


UK Tidal Resources



Source: Carbon Trust

Average Mean Wave Power



EMEC – Trial platform « Waves and swell »

EMEC ORKNEY

WAVE TEST SITE

Black Craig Observation Point

Coastguard lookout station converted to house powerful camera for monitoring activity at sea. Camera controlled from data centre and pictures transmitted onto website.



Stormness substation



EMEC Office/Data Centre

EMEC has a suite of offices and data acquisition facilities, including areas dedicated to specific developers.

Fibre optic and VHF networks provide developers with direct access to their own devices.



Stormness harbour

Billia Croo Substation



Housing main switchgear, back-up generator and comms room, controls for supply from each offshore device, and for connection to National Grid. Carefully designed to minimise environmental impact.

Met Station

Onshore station providing realtime weather data to data centre.



Test berth marker buoy

Test Berths

Four 11 kV subsea cables extend to 50 m water depth, 1-2 km from shore at locations 0.5 km apart. Developers will install moorings, connecting cable, and then their generating device.



Device moorings being installed

Waverider Buoys

Two waverider buoys measure wave height, length, direction and transmit realtime data back to main office.



Sandy seabed at test site

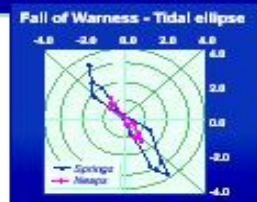
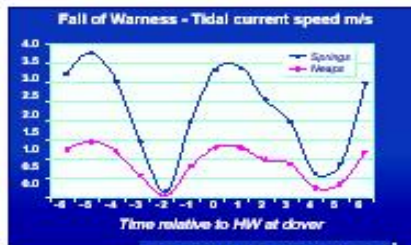


Storm waves at Black Craig

EMEC – Trial Platform « sea currents »



TIDAL TEST SITES



Falls of Warness, tidal stream flows up to 3.5 m/s springs, 1.5 m/s neaps.

Existing 33 kV and 11kV grid network on Eday.



Tides flow up to 5 m/s between and around the islands.



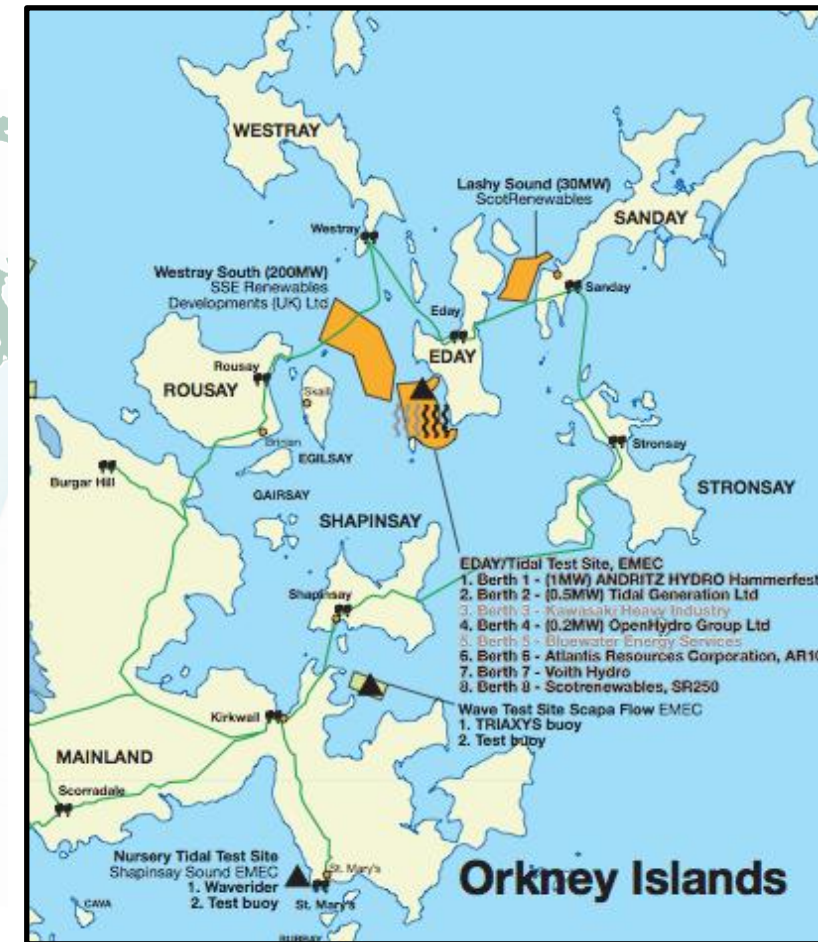
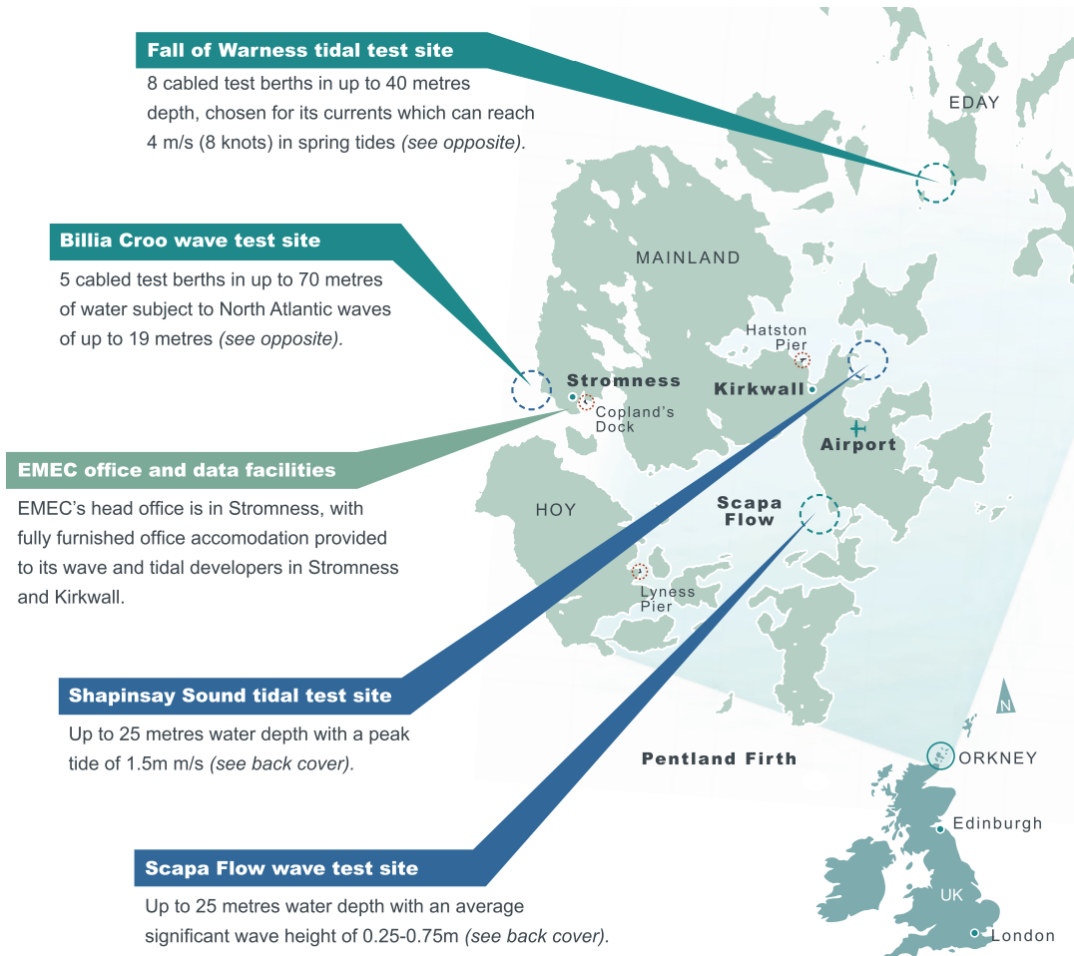
ADDITIONNAL INFORMATION : TESTS SITES



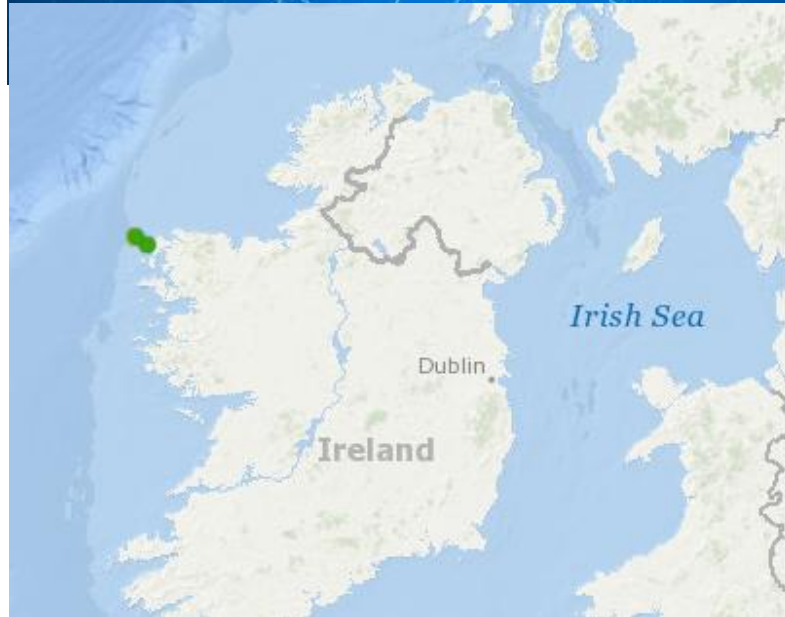
Worldwide tests sites



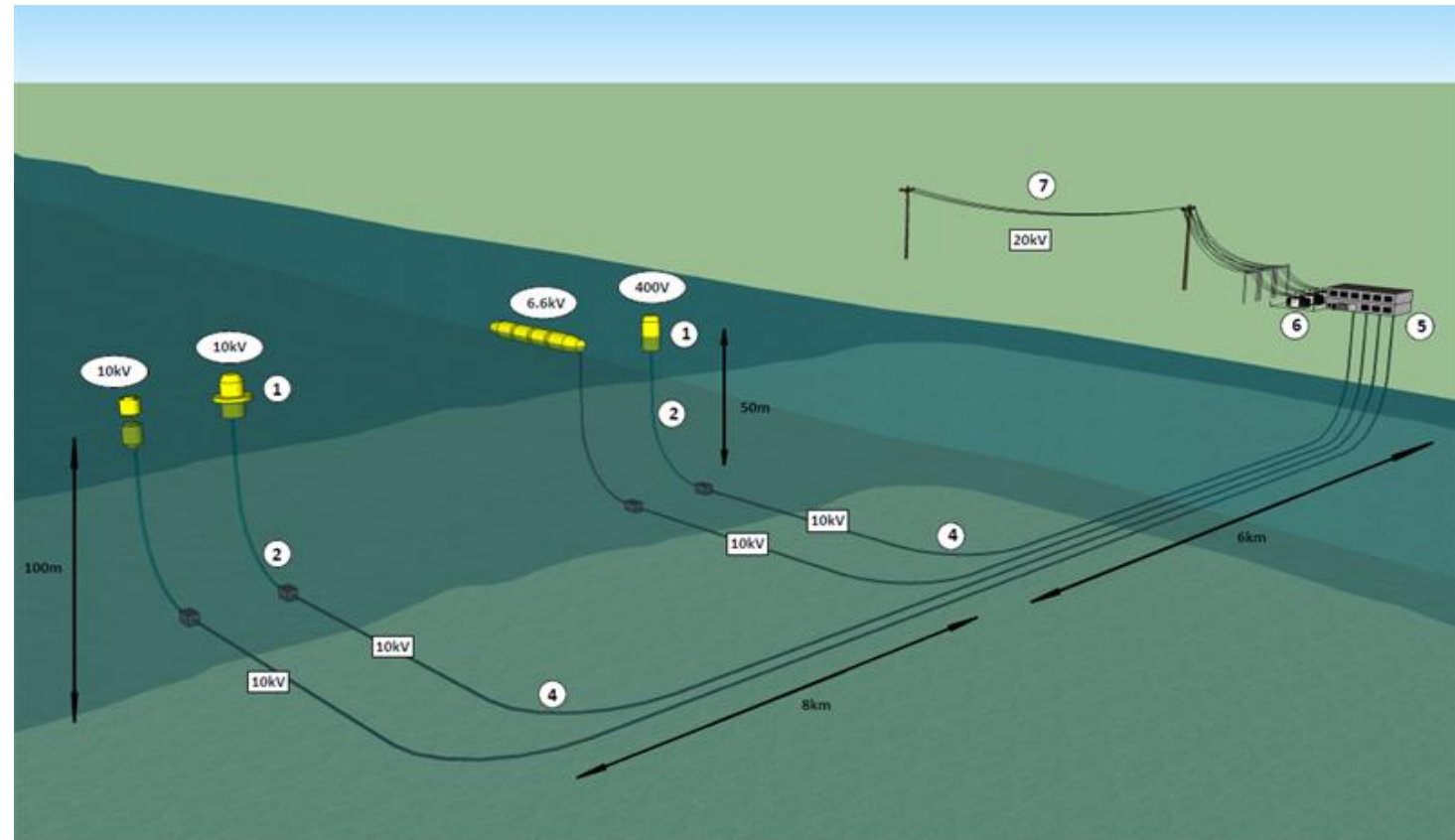
EMEC (European Marine Energy Center) Scotland



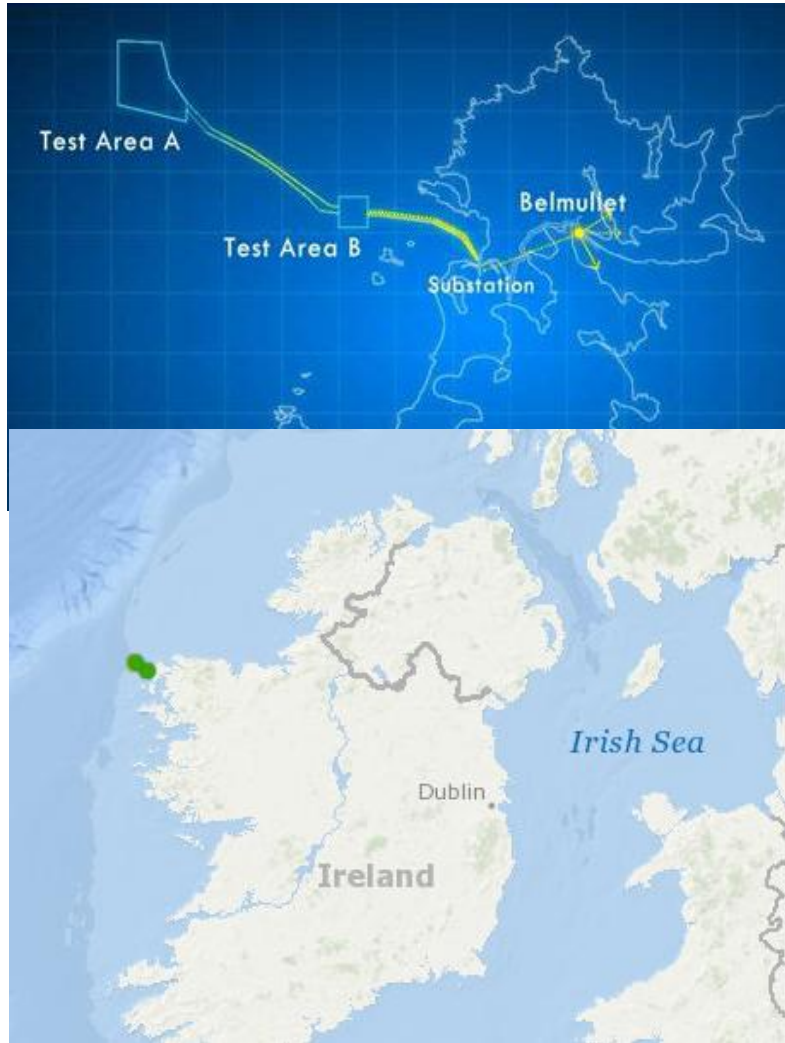
Ireland – Atlantic Marine Energy Test Site (AMETS)



- **Test Area A** : Wd = 100 m, 16 km offshore - 6,9 km² area
- **Test Area B** : Wd = 50 m, 6 km offshore - 1,5 km² area
- **Substation and grid connection**



Atlantic Marine Energy Test Site (AMETS) - Ireland



The Atlantic Marine Energy Test Site (AMETS) is being developed by Sustainable Energy Authority of Ireland (SEAI) to facilitate testing of full-scale wave energy converters and floating offshore wind technologies in an open ocean environment.

AMETS will be located off Annagh Head, west of Belmullet in County Mayo and will be connected to the national grid. The test site is an integral component of Ireland's Ocean Energy Strategy and is being developed in accordance with the national Offshore Renewable Energy Development Plan (OREDPP).

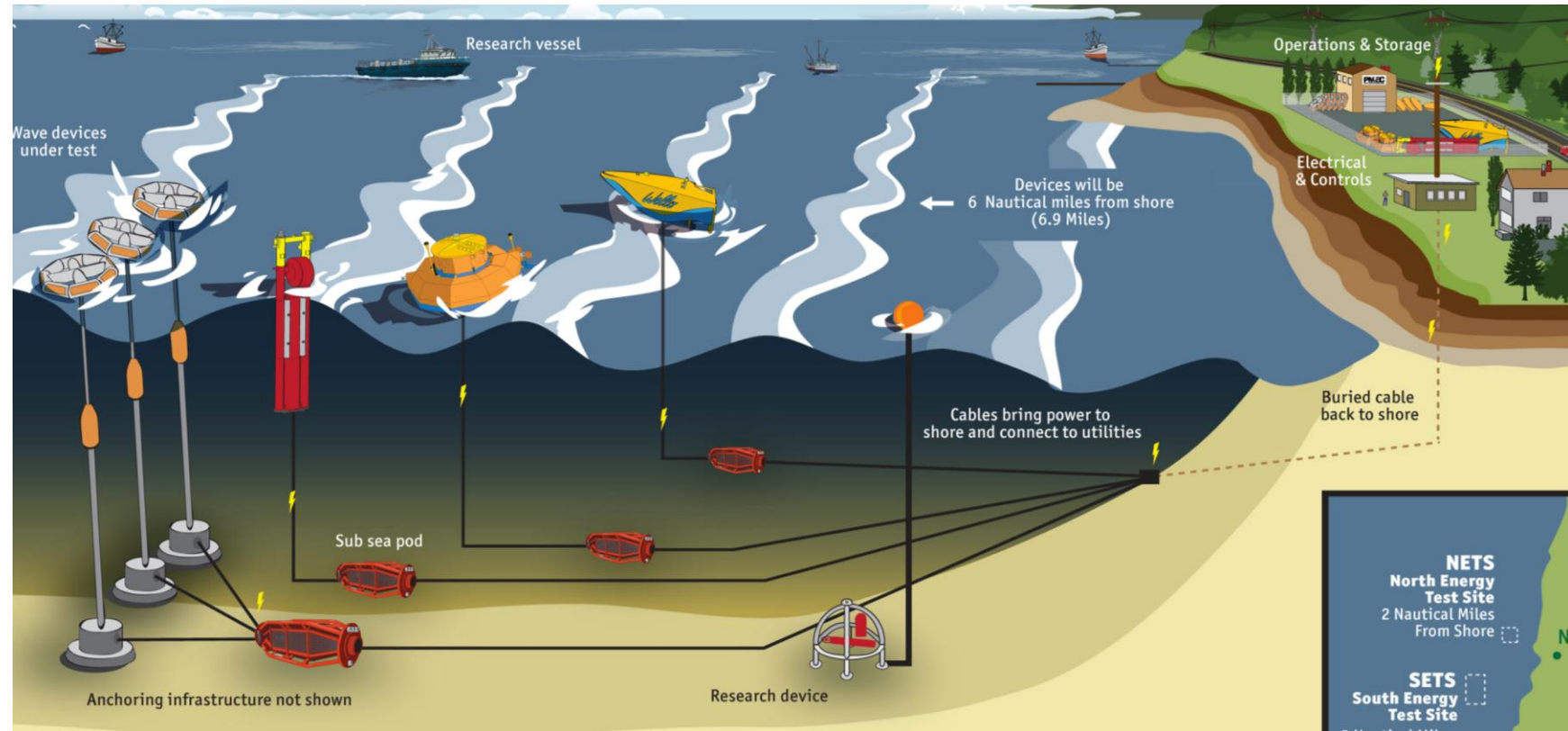
The site will be focused on wave and wind energy and will provide two separate test locations at various depths of water to allow for a range of devices to be tested. The test site will provide a grid connected national test facility, to which full scale wave energy converters and floating offshore wind technologies could be coupled during their final stages of pre-commercial development.



FORCE (Funding Ocean Resources Center Energy) - Canada

- About 160 billion tonnes of water flows through the Bay of Fundy at each tide.
- About 4 billion tonnes of that water passes through the Minas Passage.
- Creating the highest tides in the world with a speed of 18 km/h, rising up to 16 m.

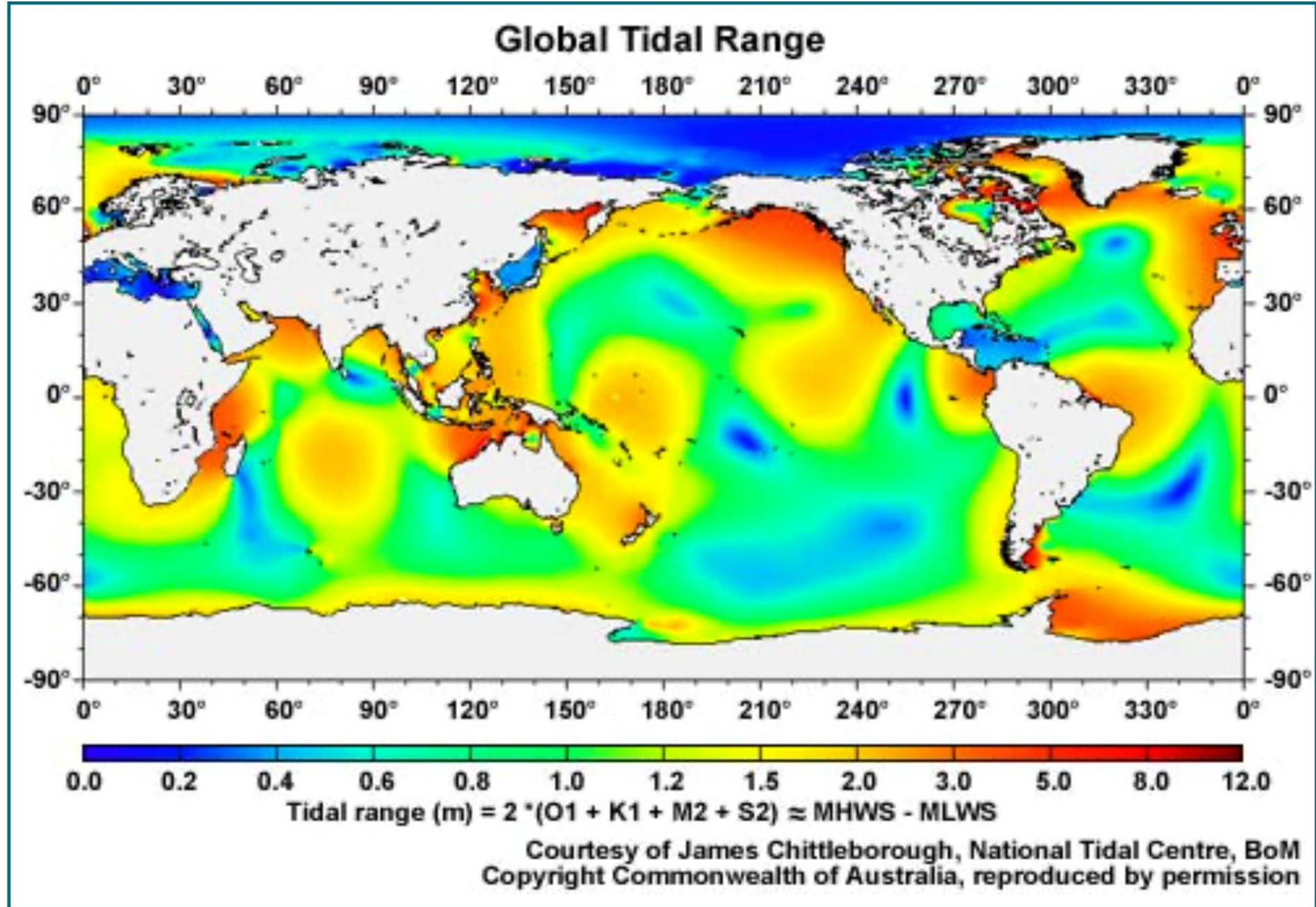




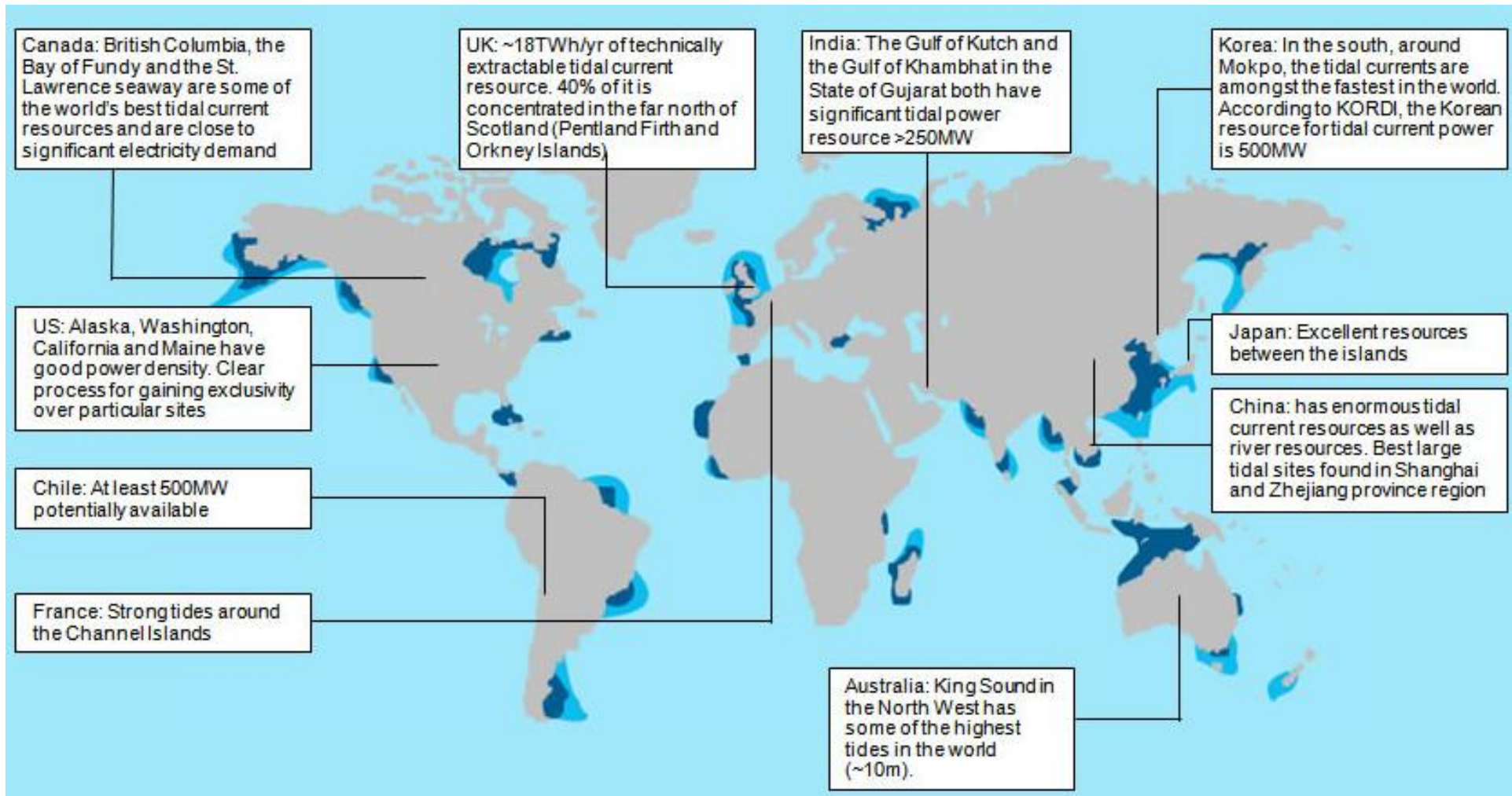
6-3

Tidal Energy



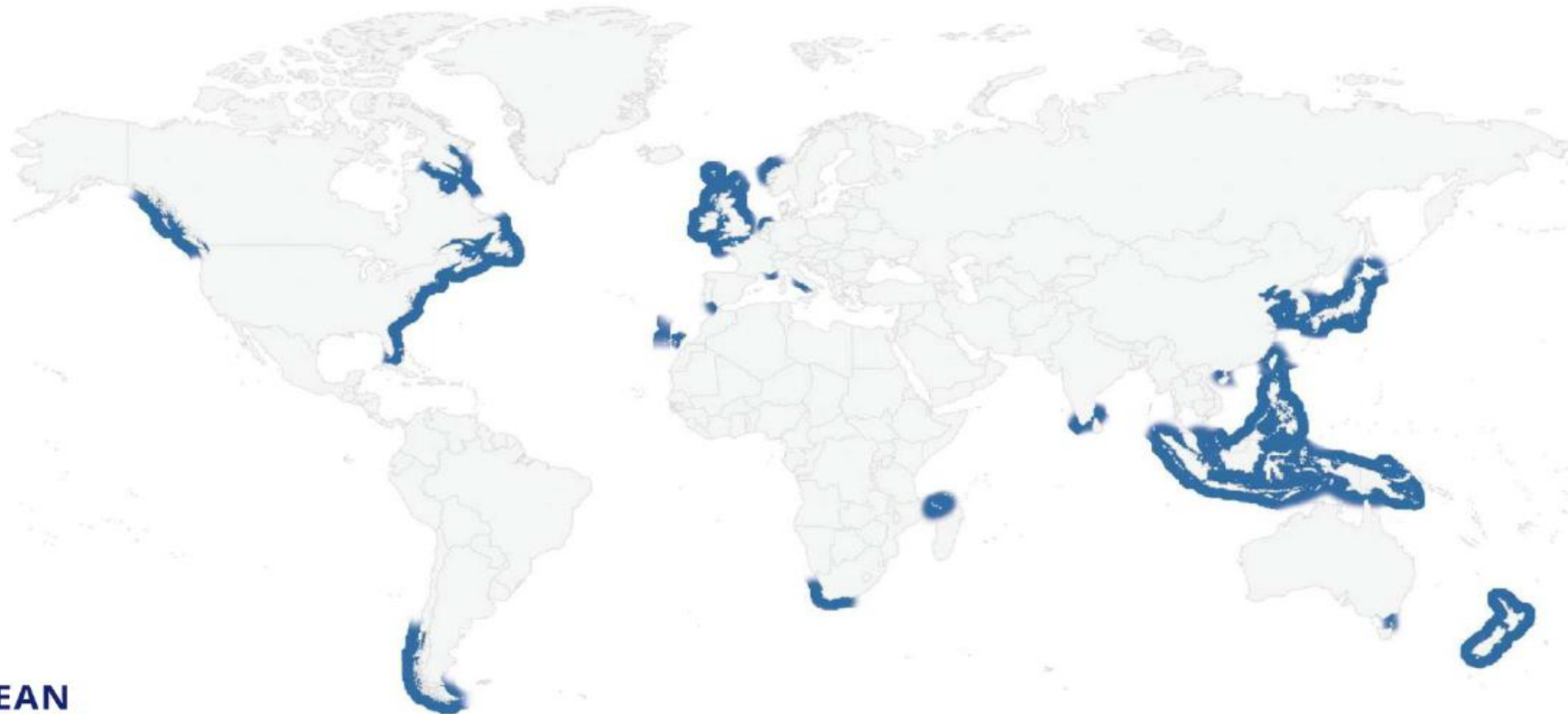


Areas with high potential Tidal Resources



Areas with high potential Tidal Ressources

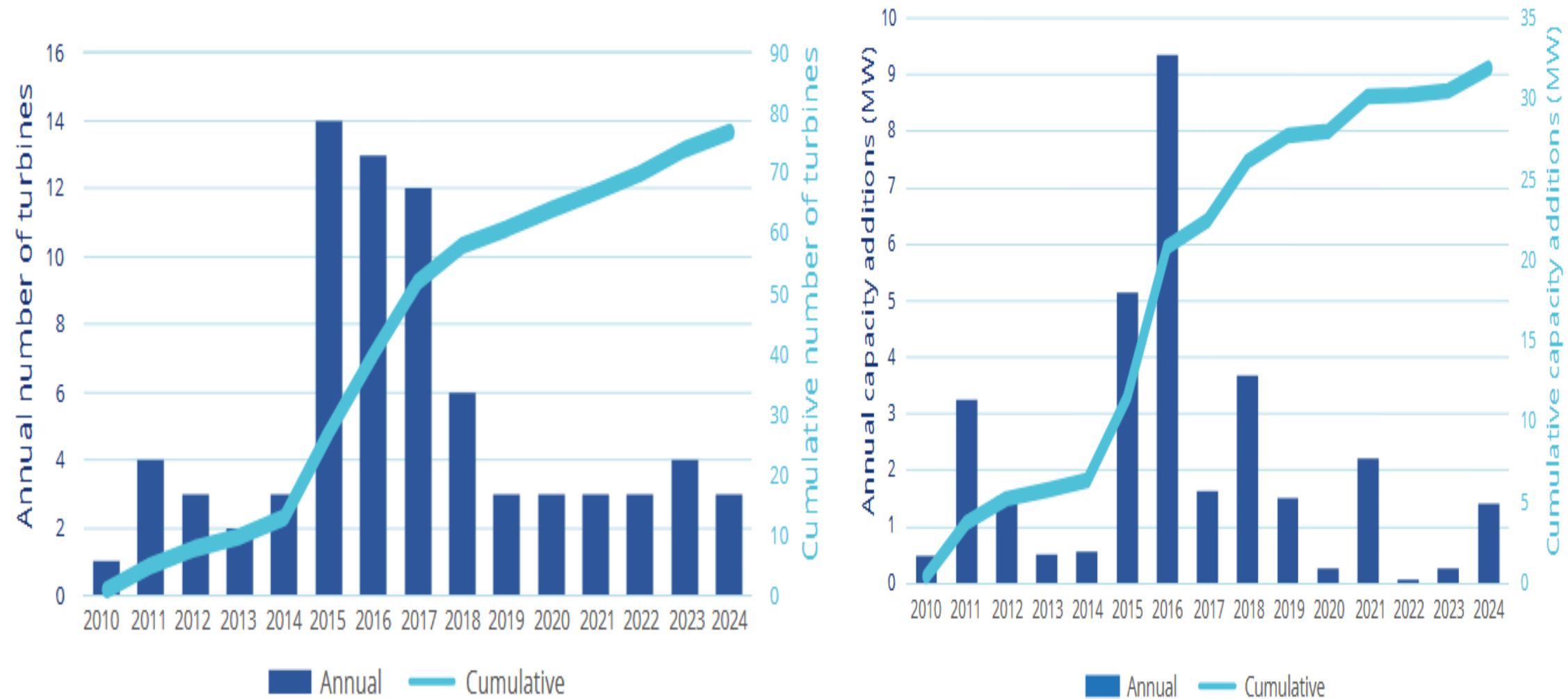
Global Tidal Resource



Source: Ocean Energy Europe - 2026



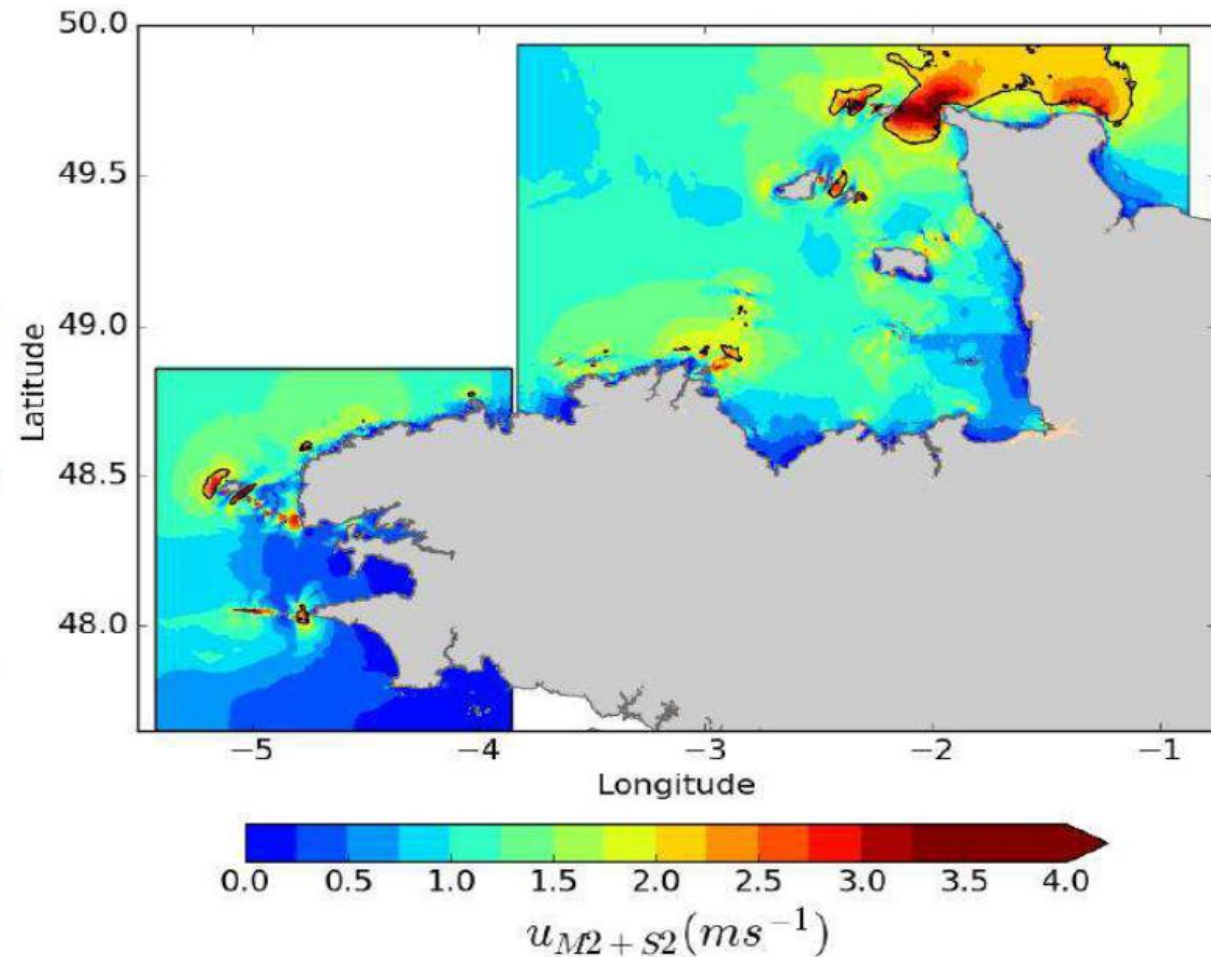
Tidal stream in Europe: Number of Turbines & Installed Capacities



Tidal resources in Europe: UK & France

UK & France have best tidal resource

- More geographically limited than wave
- Tidal current speed (m / sec)
- 14 million litres pass thru 1m³ in 1 hour at max speed
- ~6 Olympic swimming pools



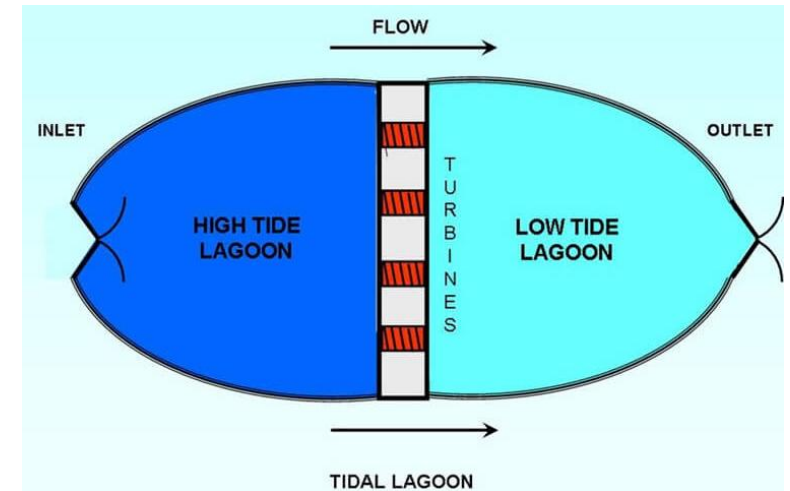
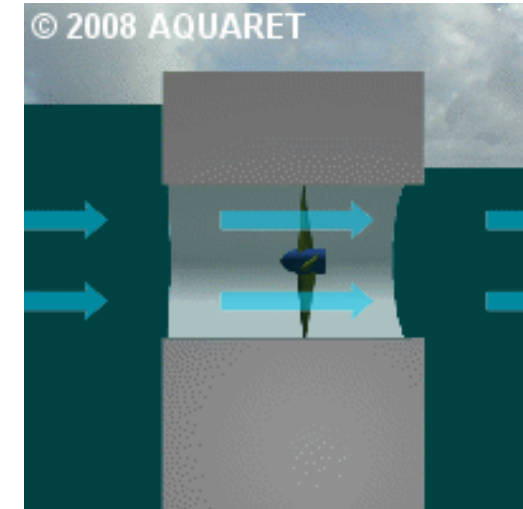
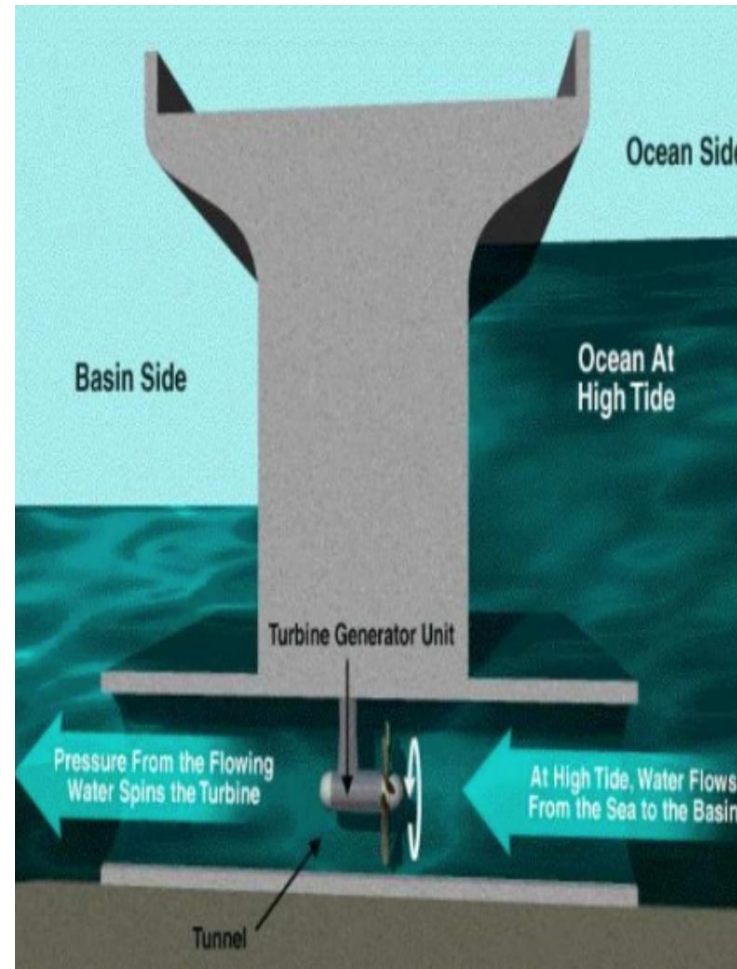
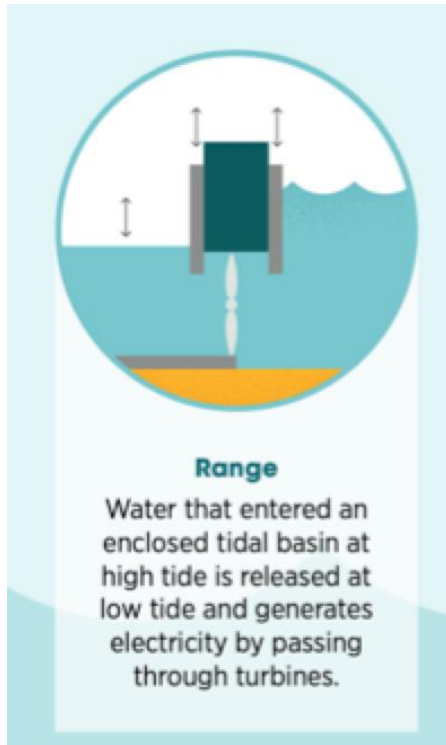
Source: Renewable resource assessment, European region (December 2022), EU-Scores project



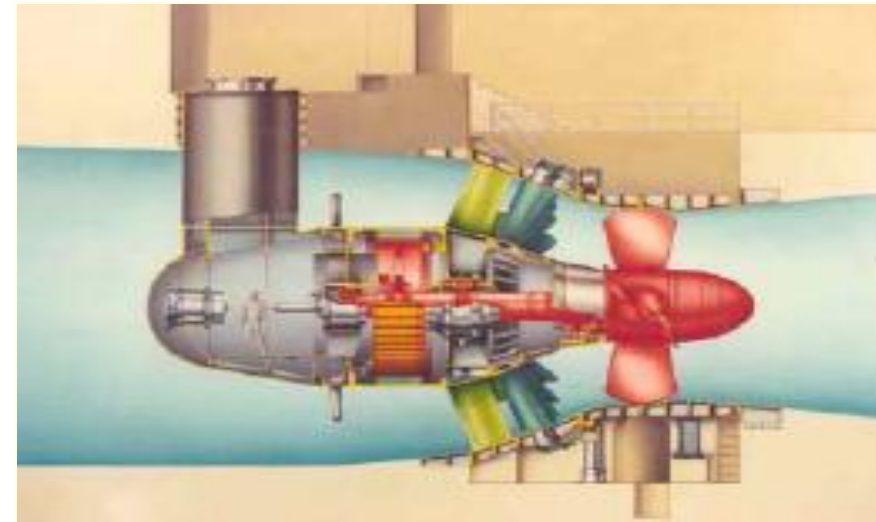
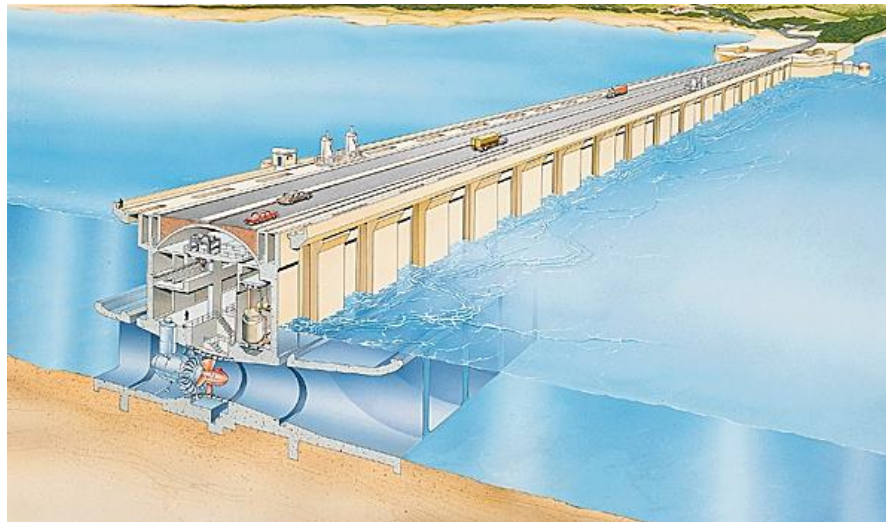
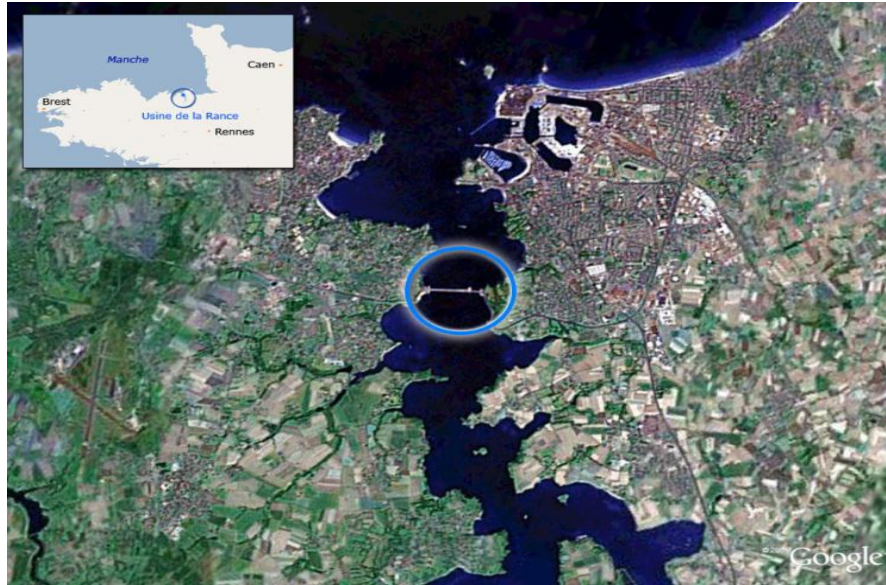
Tidal stream deployments in Europe in 2024

Map ref.	Country	Location	Device developer	Device name	Type	Capacity (kW)	No. of devices	Scale
1	DENMARK	Faroe Islands	Minesto	Dragon 12	Kite	1200	1	Full-scale
2	NETHERLANDS	Ameland	SeaCurrent	TidalKite	Kite	200	1	3:5
3	UK	Strangford Lough, Northern Ireland	ORPC Ireland	X-Flow Project Turbine	Horizontal Axis	18	1	Test-scale

Tidal barrages principles



Rance Tidal Power Station 240 MW (1967) - France



Rance Tidal Power Station 240 MW (1967) - France

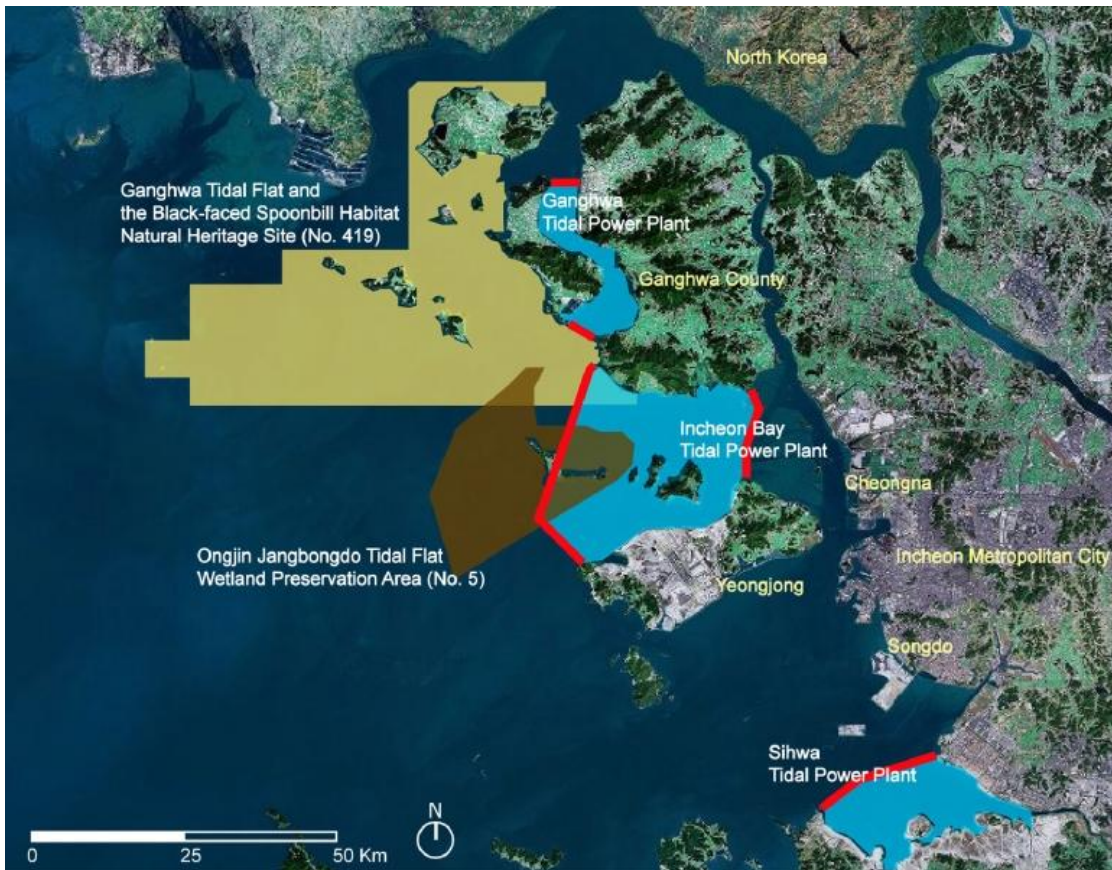


Rance Tidal Power Station - France

- **Opened on 26 november 1966**
 - **240 MW = 45% of World Marine Energy Capacity**
 - **24 turbines, 10 MW each**
 - **Capacity factor: 26%**
 - **Length: 700 m**
 - **Annual output: 540 GWh**
 - **Capex: 620 MFF = 95 M€ 1966**
 - **Capex: # 860 M€ 2019 (CPI corrected)**
 - **Present Production Cost: n.a.**
 - **LCOE if rebuilt today at equivalent Capex > 130 €/MWh**
-
- **P.m: Sihwa Lake power station (South Korea): 254 MW**
Start-up on 4 august 2011



Sihwa Lake Tidal 254 MW project (2012) – South Korea



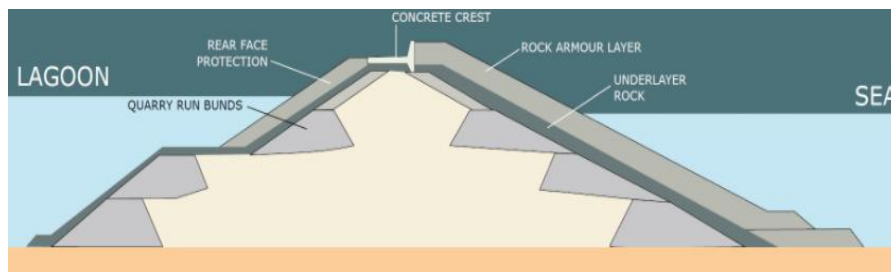
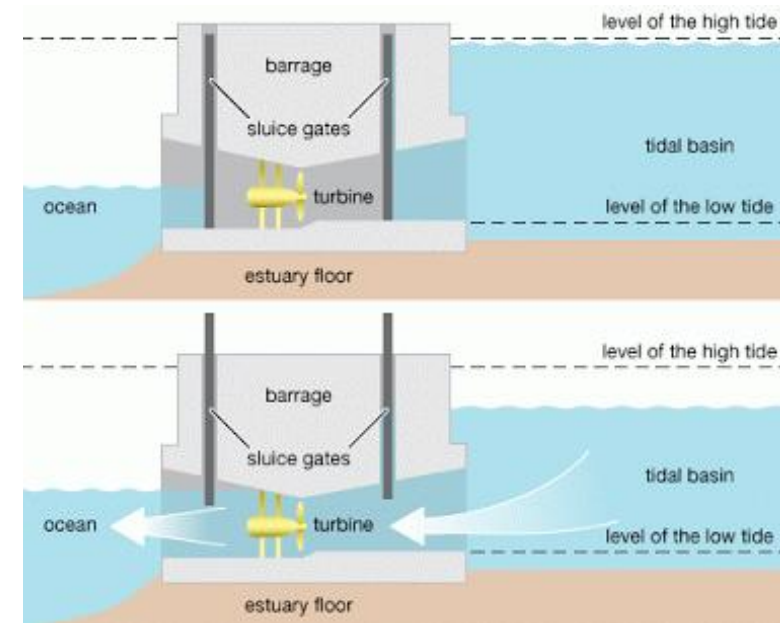
Several Tidal Lagoon Projects in UK

Wales project : Swansea – Tidal Lagoon Power

- 320 MW
- Length = 9,5 km
- Artificial lagoon area : 11,5 km²
- Delta tidal = 4,1m – 8,5m
- CO₂ saving = 236,000 tons/year
- Green light? Operational start-up?
- **Many debates** on this project.....



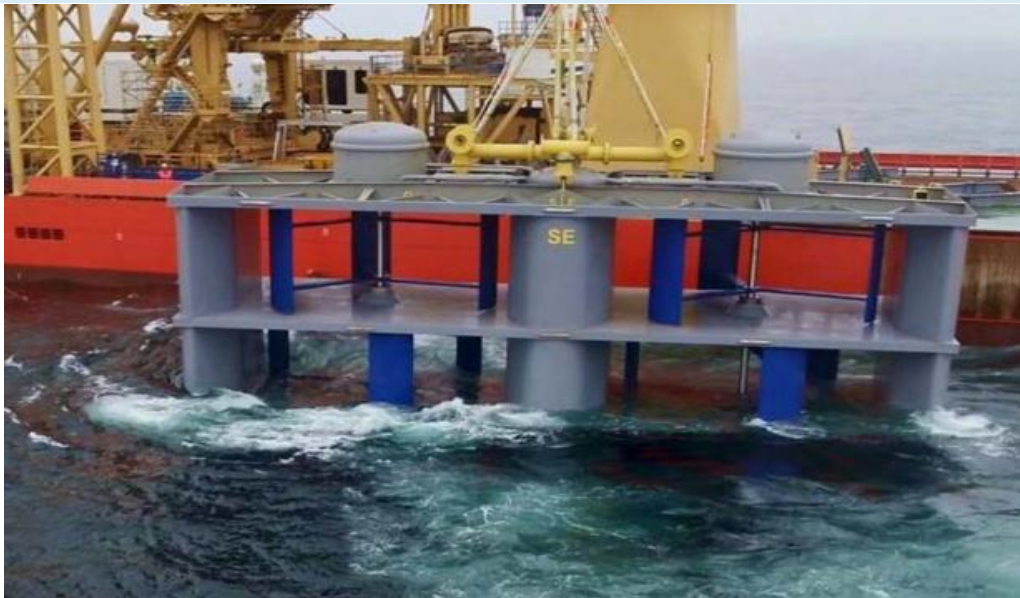
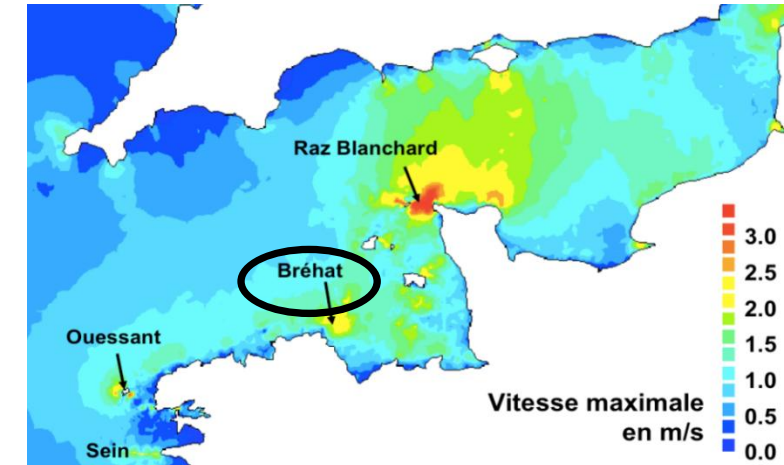
Proposed Tidal Lagoon 320 MW project Swansea Bay - Wales



Hydroquest 1MW project at Brehat test site - France

Building on its longstanding experience generating power from rivers, HydroQuest partnered with Constructions Mécaniques de Normandie to produce its first tidal turbine. The 1 MW HydroQuest Ocean device was successfully installed on the EDF-run site of Paimpol Bréhat in Brittany during the summer.

The project is breathing new life into the test site. It will generate valuable hours of operational experience and data, enabling the developers to prove the capability and reliability of their technology.



Tests
Length : 25 m
Height : 11 m
Weight : 400 tons
Power : 1 MW
2017-2019



ANDRIZ HYDRO Hammerfest Tidal Stream - Norway

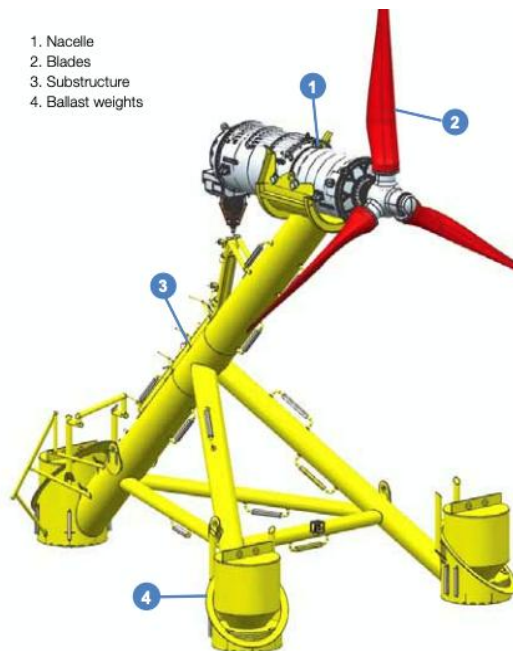
Prototype Technology developed by ABB, Rolls-Royce, Equinor in 2003

- ◆ Pilot 300 kW 200tons
- ◆ Site : Kvalsund in WD=50m
- ◆ 2010 : technology purchased by Andritz
- ◆ Retrieved in 2012

Technical characteristics

Rated power:	500-2,000 kW (site dependant)
Power regulation:	Variable pitch, yawing system, variable speed
Operating depth:	35-100 m
Rotor:	
Type:	3 bladed open
Rotor swept area:	300-500 m ²
Nominal speed:	approx. 10 rpm
Generator:	
Type:	Induction
Nominal output:	500-2,000 kW
Weight:	
Nacelle:	approx. 130 t
Substructure:	approx. 150 t
Installation:	Heavy lift vessel/barge (with ROV support)
Lifetime/Service:	25 years/every 5 years

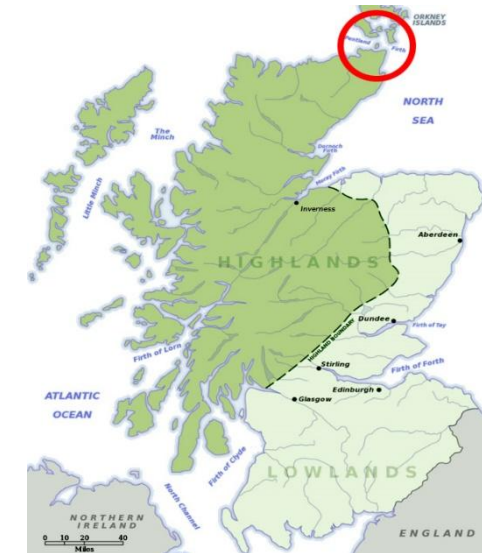
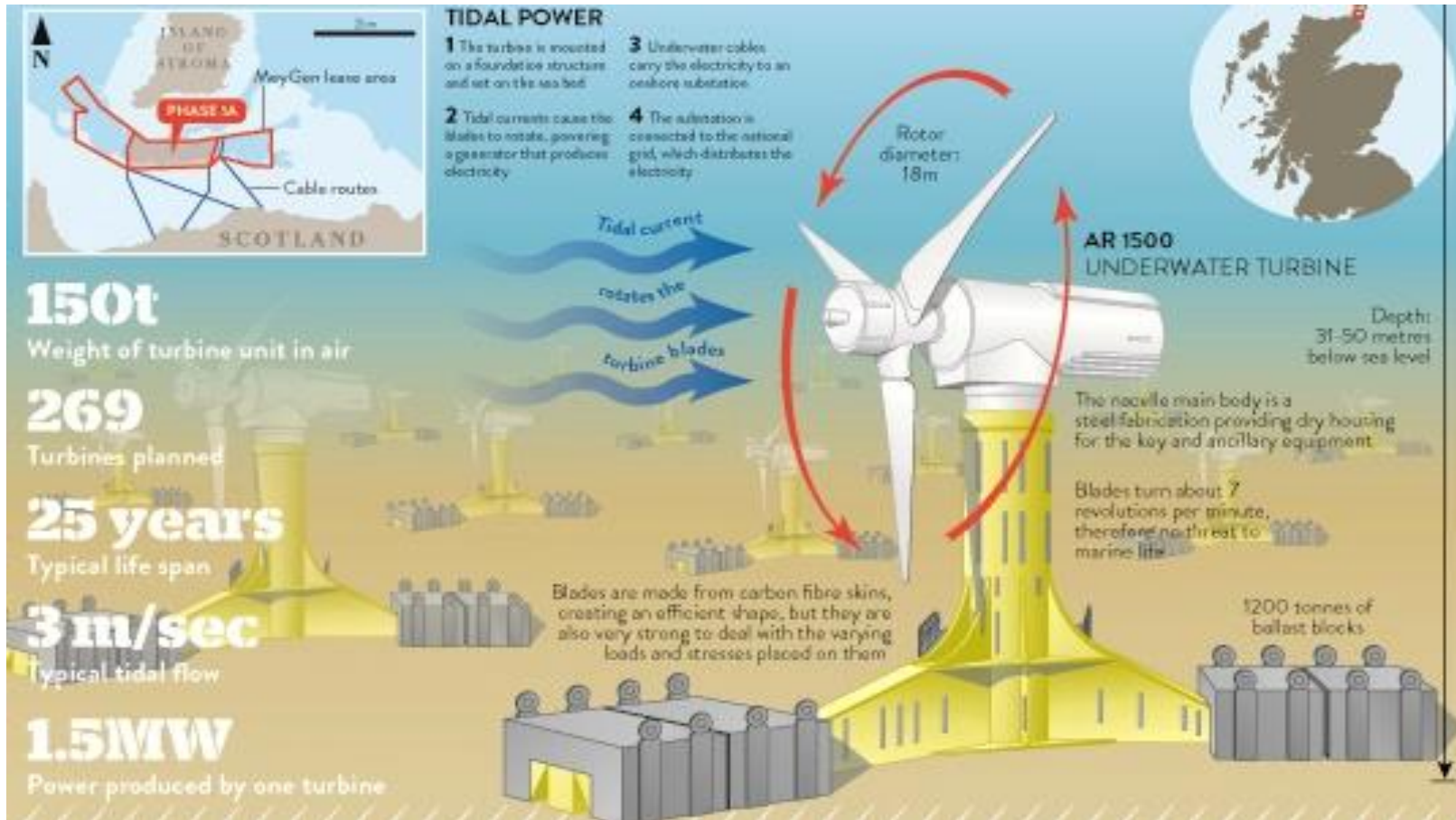
1. Nacelle
2. Blades
3. Substructure
4. Ballast weights



HS1000 turbine technology installed at the EMEC (European Marine Energy Center) in 2011. Andritz Hydro Hammerfest has developed a 1,5 MW MK1 turbine. 3 of which have been installed as part of the **Meygen project** in the Pentland Firth.



Atlantis Meygen 12 MW project - Scotland



Orbital Marine Power – Orkney Islands

TotalEnergies Partner

- ◆ Development of cost effective tidal hydrokinetic turbines. Technology from oil and gas, designed for minimum on-site work. Testing at EMEC (European Marine Energy Center Ltd.)
- ◆ 2003: 1/16th scale model
- ◆ 2005: 1/7th scale model
- ◆ 2011: SR 250, 250 kW floating tidal turbine prototype at sea operational in Orkneys (EMEC)
- ◆ 2015/2016: SR 2000, 2 MW turbine, as at August 2018, 3 GWh of electricity produced
- ◆ 2021/2022 : O2



Orbital Marine Power – Orkney Islands: Tidal Hydrokinetic Turbines

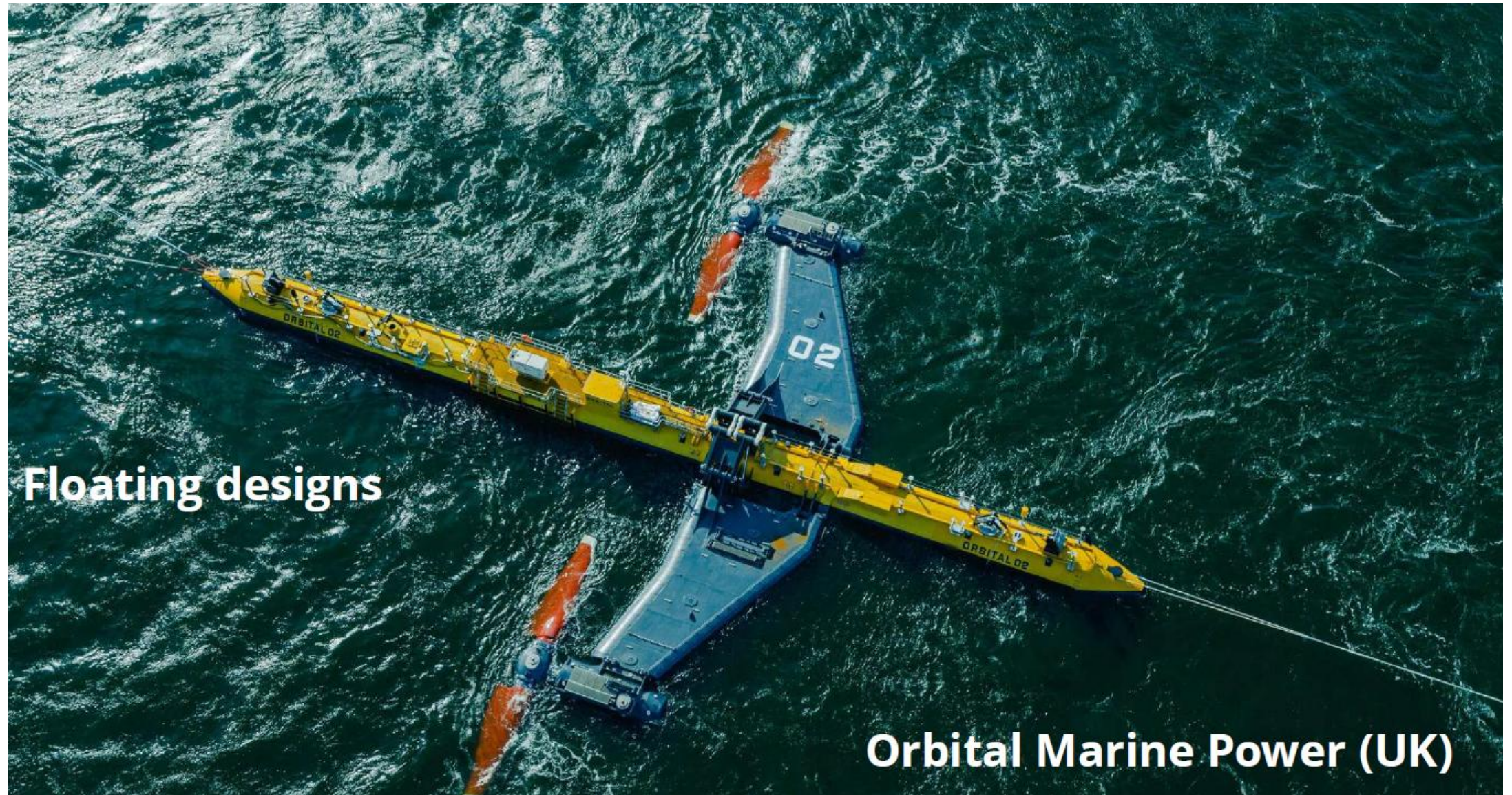


Source: Orbital Marine Power

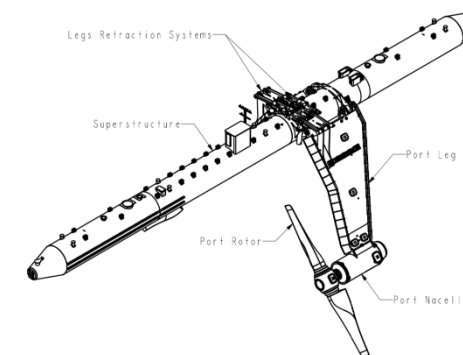
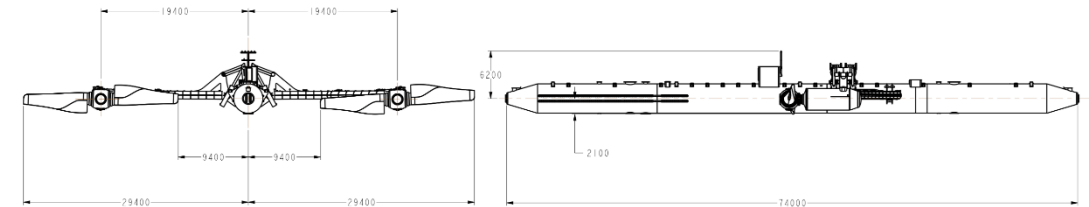
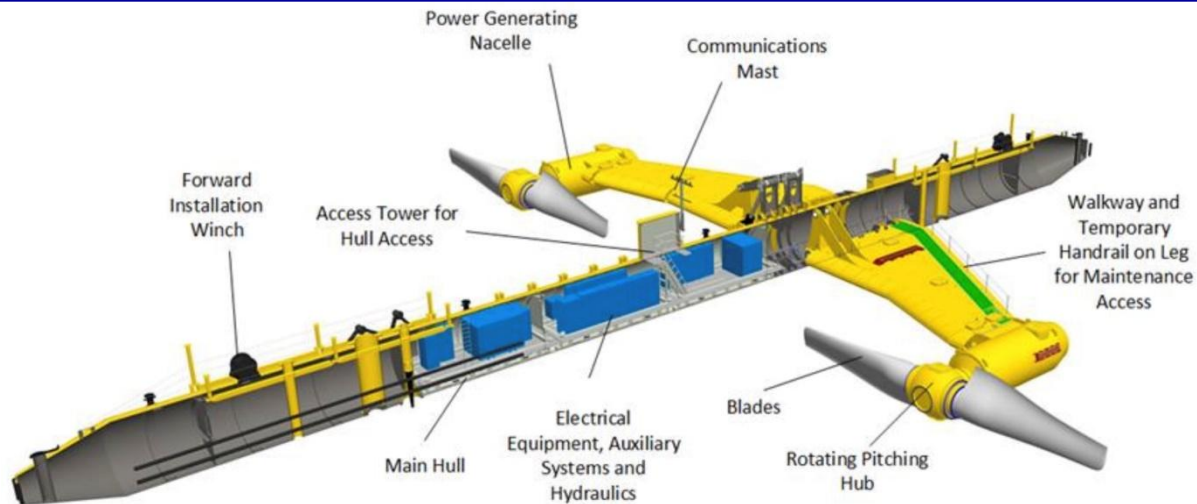
526

TPA Toolbox Energy Book 7 – Renewables

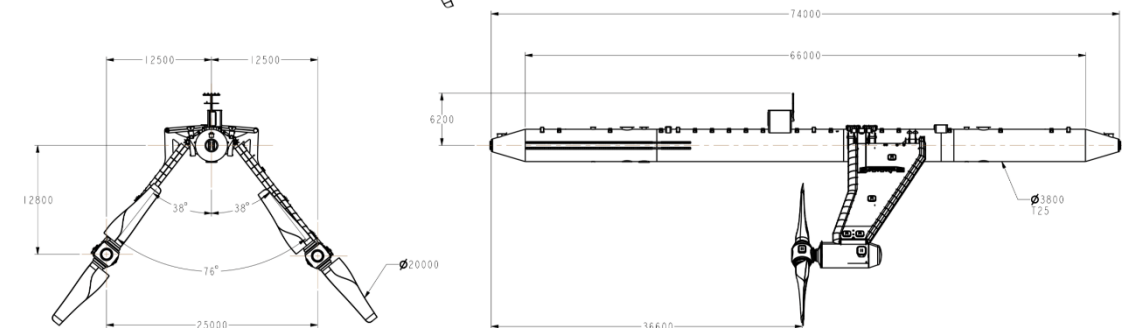
Orbital Marine Power – Orkney Islands: Tidal Hydrokinetic Turbines



Orbital Marine Power : O2 prototype



Ongoing Tests
O2
Power 2MW
600 tons



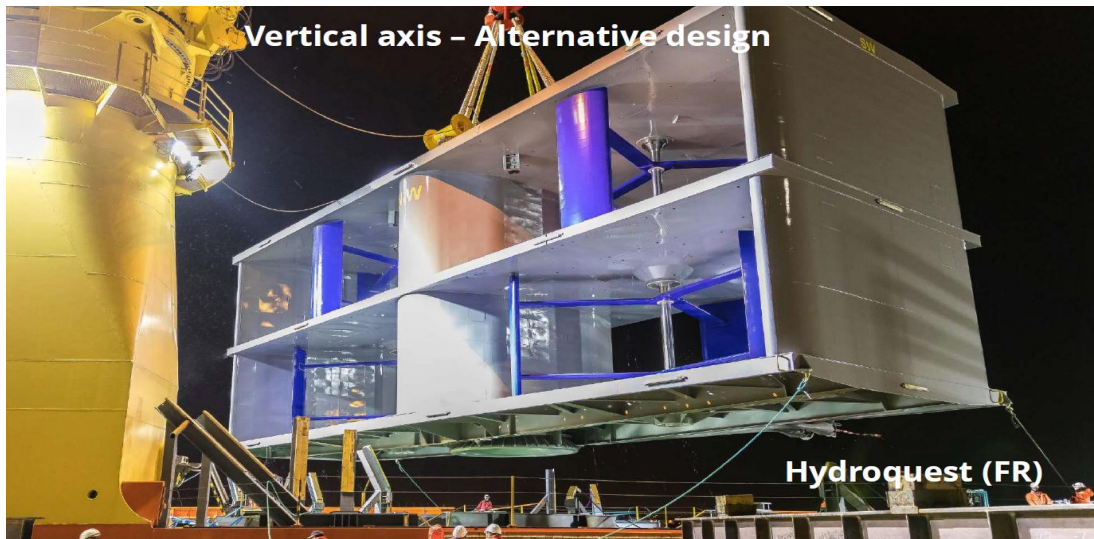
Summary of device characteristics	
Rated power	c. 2 MW
Displacement	600 metric Tonnes approx.
Rated current speed	2.5 m/s
Cut-in current speed	1 m/s
Shut down current speed	4.5 m/s
Hull length overall	74 m
Diameter of Hull tube	3.8 m
Depth to uppermost rotor tip during operation (rotors extended)	3.2 m
Depth to bottom rotor tip (deepest point) during operation (rotors extended)	23.2 m
Maximum depth of rotors below surface when rotors retracted	2.3 m
Maximum depth of platform below waterline	2.3 m
Height of hull tube exposed above the water surface	1.5 m
Maximum rotation speed	15 rpm
Rotor diameter	20 m
Rotor swept area	2 x 314 m ²



Orbital Marine Power : O2 under test in Orkney Island



Tidal Energy: various technologies



6-4

Wave Energy

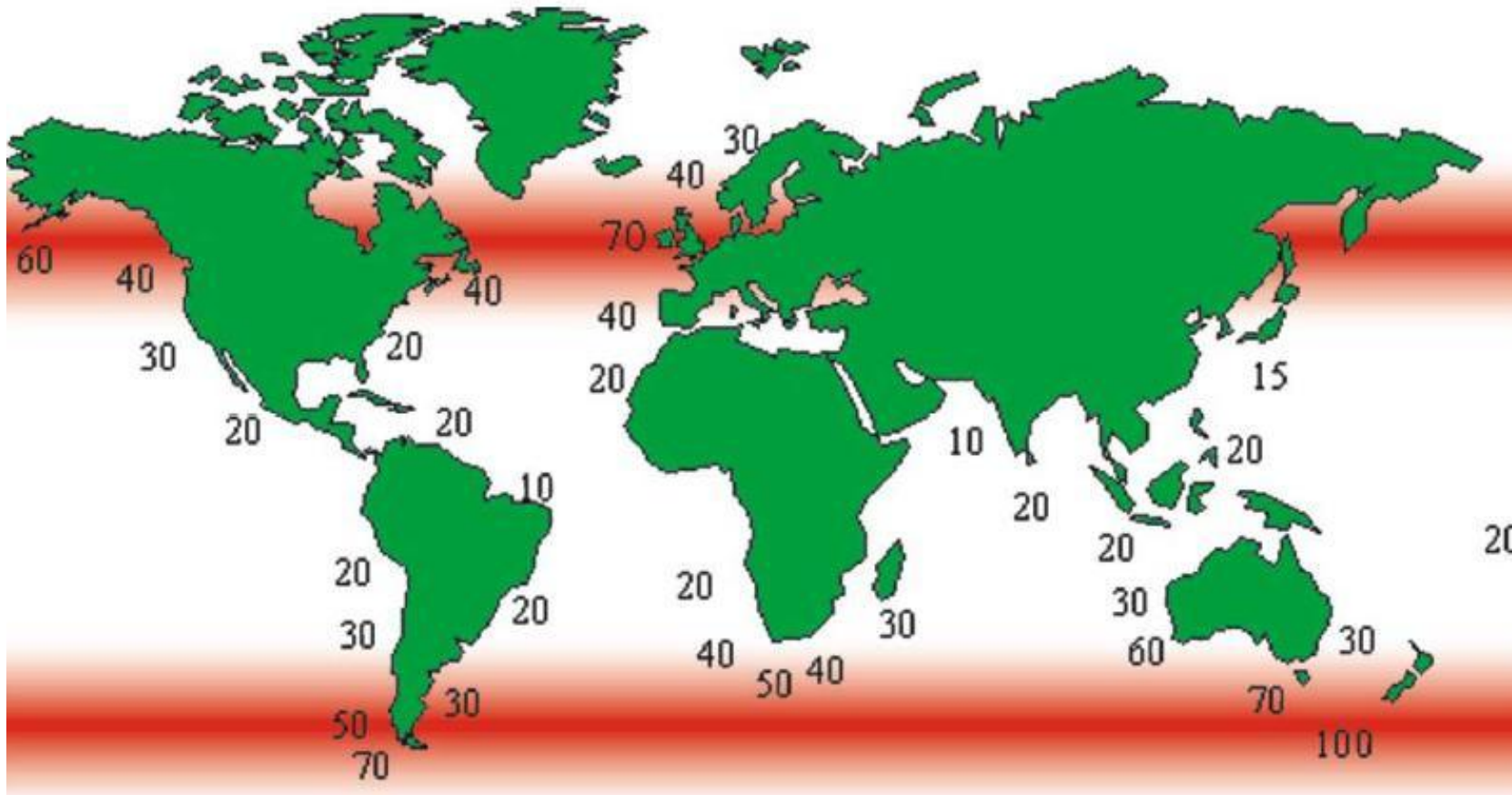


Wave Energy potential

Wave Energy: largest untapped renewable resource



Energy potential form in (kW/m)



- ◆ The energy potential is estimated in Kw / meter of wave front
- ◆ This energy is proportionnal to wave period
- ◆ This energy varies as the square of waves height



Energy potential form in (kW/m)

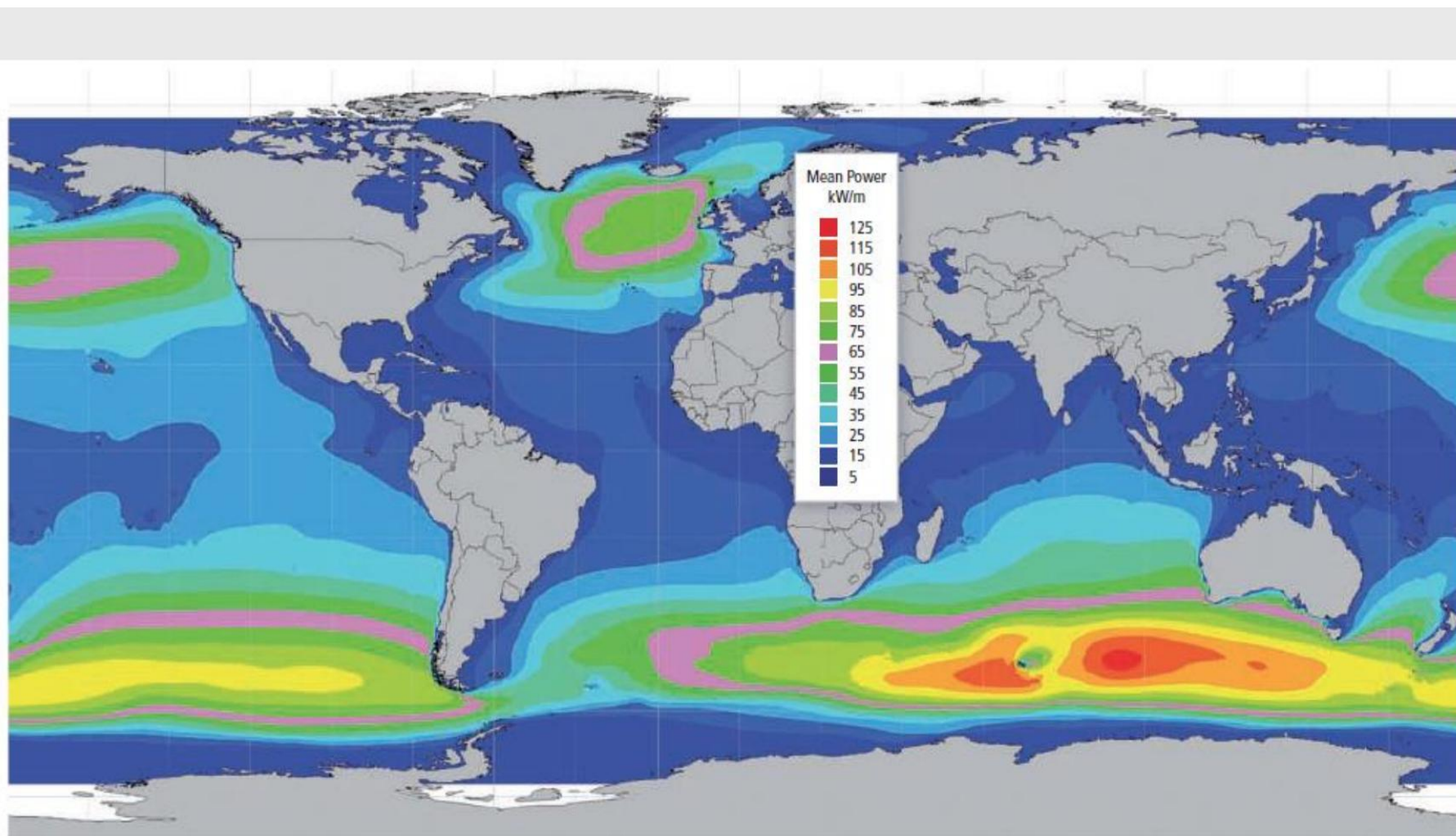


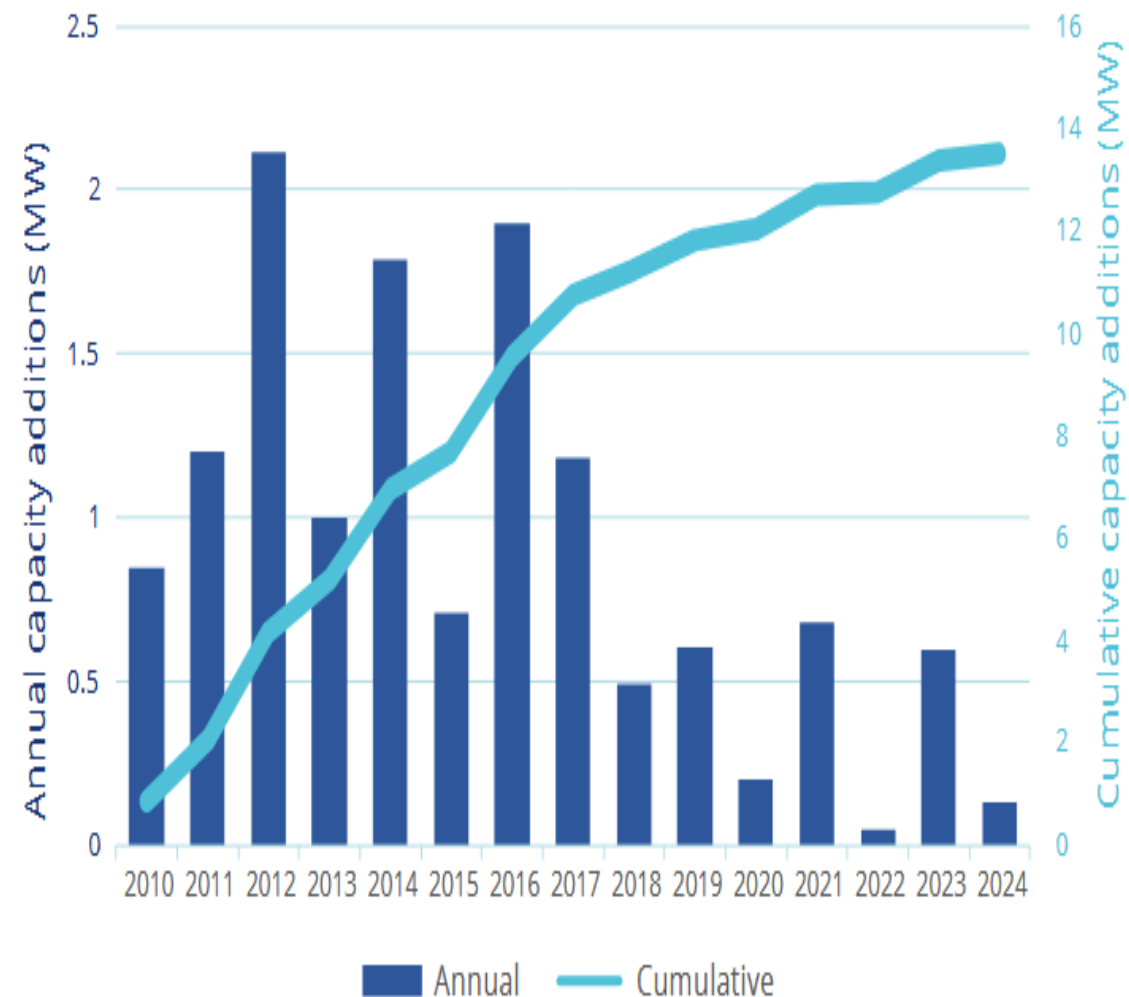
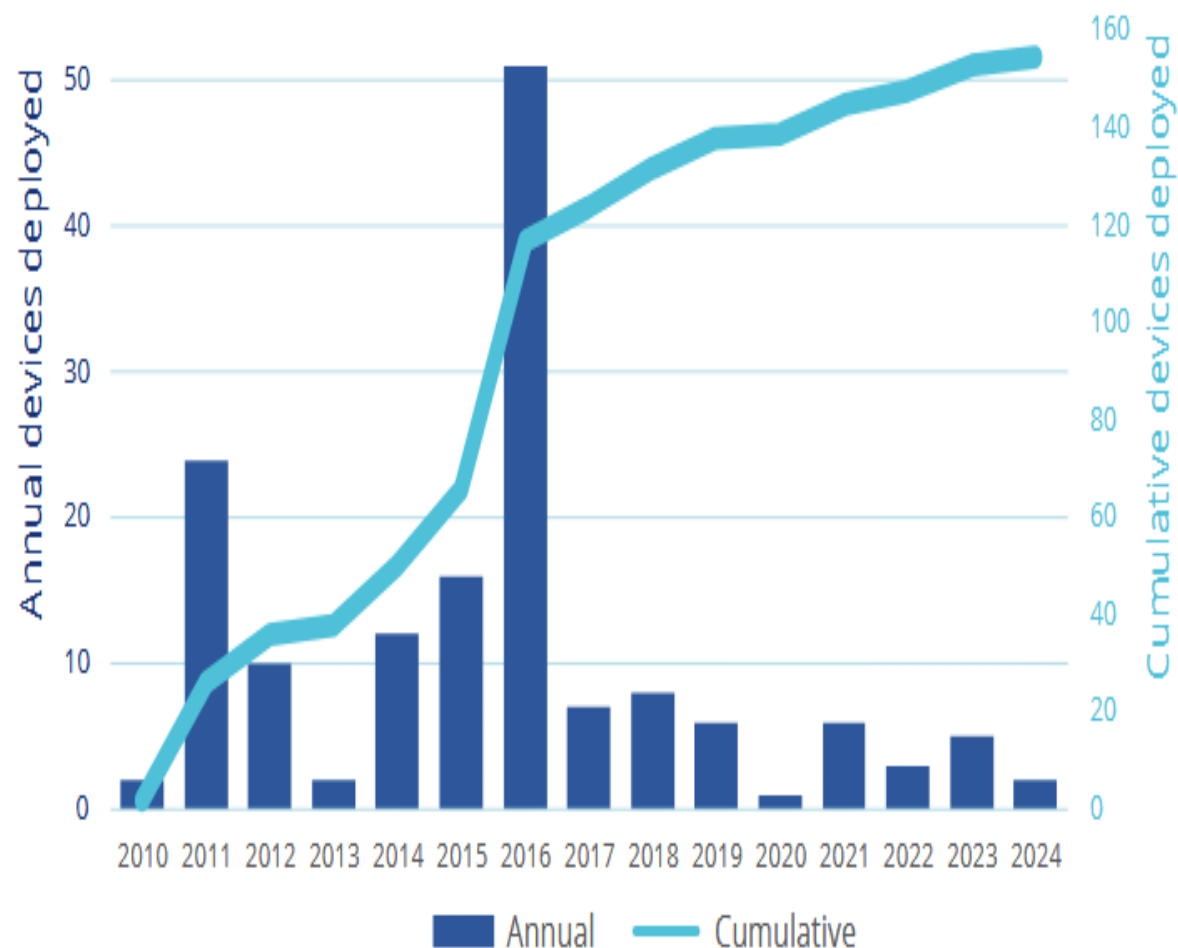
Figure 6.1 | Global offshore annual wave power level distribution (Cornett, 2008).

European Wave / Swell Energy potential (kW/m)



These energy figures are estimated at a sufficient distance of shore, around the 20 meter depth line

Wave Energy in Europe: Number of Converters & Installed Capacities



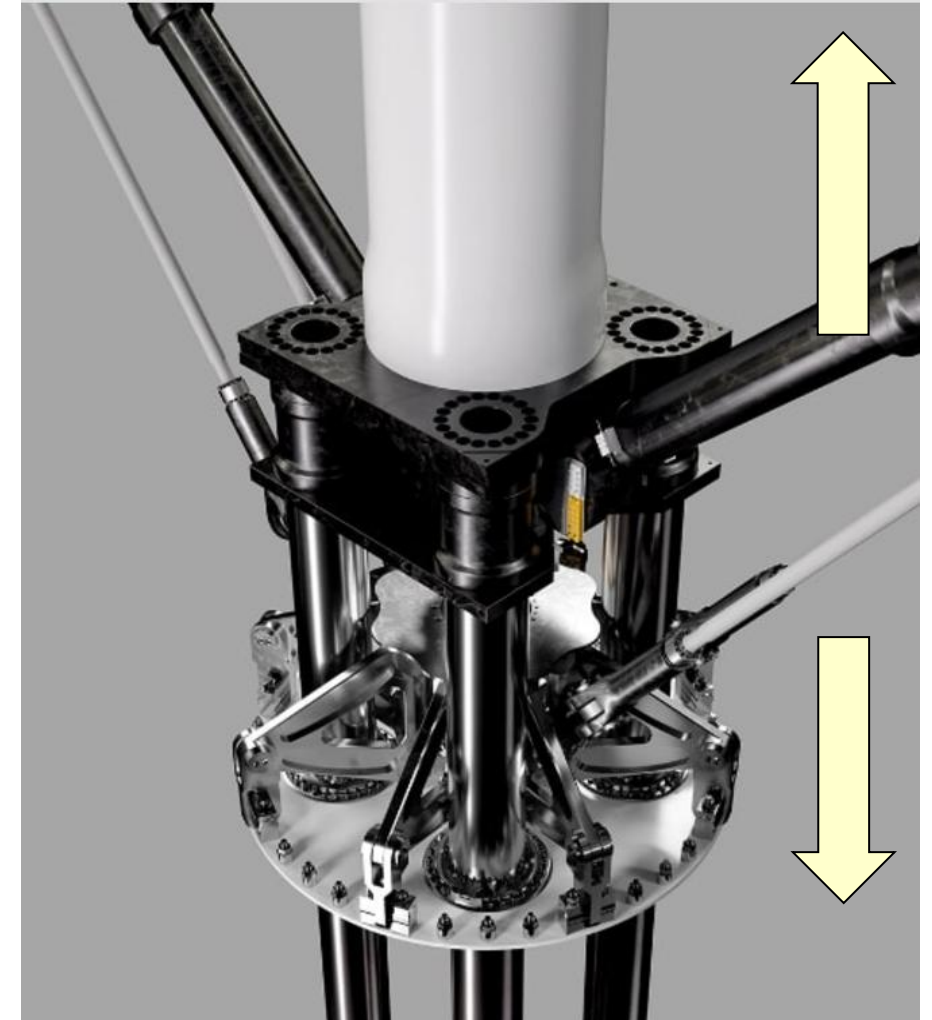
Wave Energy deployments in 2024

Map ref.	Country	Location	Device developer	Device name	Type	Capacity (kW)	No. of devices	Scale
1	SPAIN	Canary Islands	Wavepiston	Wavepiston v1	Oscillating Wave Surge String Attenuator	30	1	Full-scale
2	UK	Aberdeen, Scotland	ZOEX Power	ZOEX WEC Device	Attenuator	100	1	Full-scale

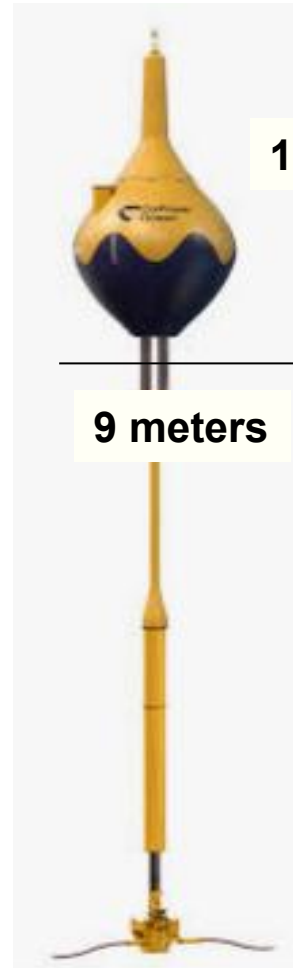


Wave Energy: A highly concentrated energy resource (from CorPower Ocean – Stockholm- Sweden)

- **Global potential of wave energy according to CorPower Ocean**
500 GW i.e 10% of the global electricity demand
1-2 GT annual CO2 emission annual avoidance
- **How CorPower Ocean's wave energy converter work?**
 - ◆ Heaving buoys on the surface go up and down and absorb energy from ocean waves.
 - ◆ Waves energy is converted into electricity through the rise and fall of buoys. The wave motion is turned into rotation by a mechanical device inside the buoy and converted into electricity by a generator .



CorPower Ocean Wave Energy converter



Characteristics:

Weight : 70 tonnes

Water depth > 40 m

Power : 300 kW

Capacity factor : 40-60%

**Current project in
Portugal**

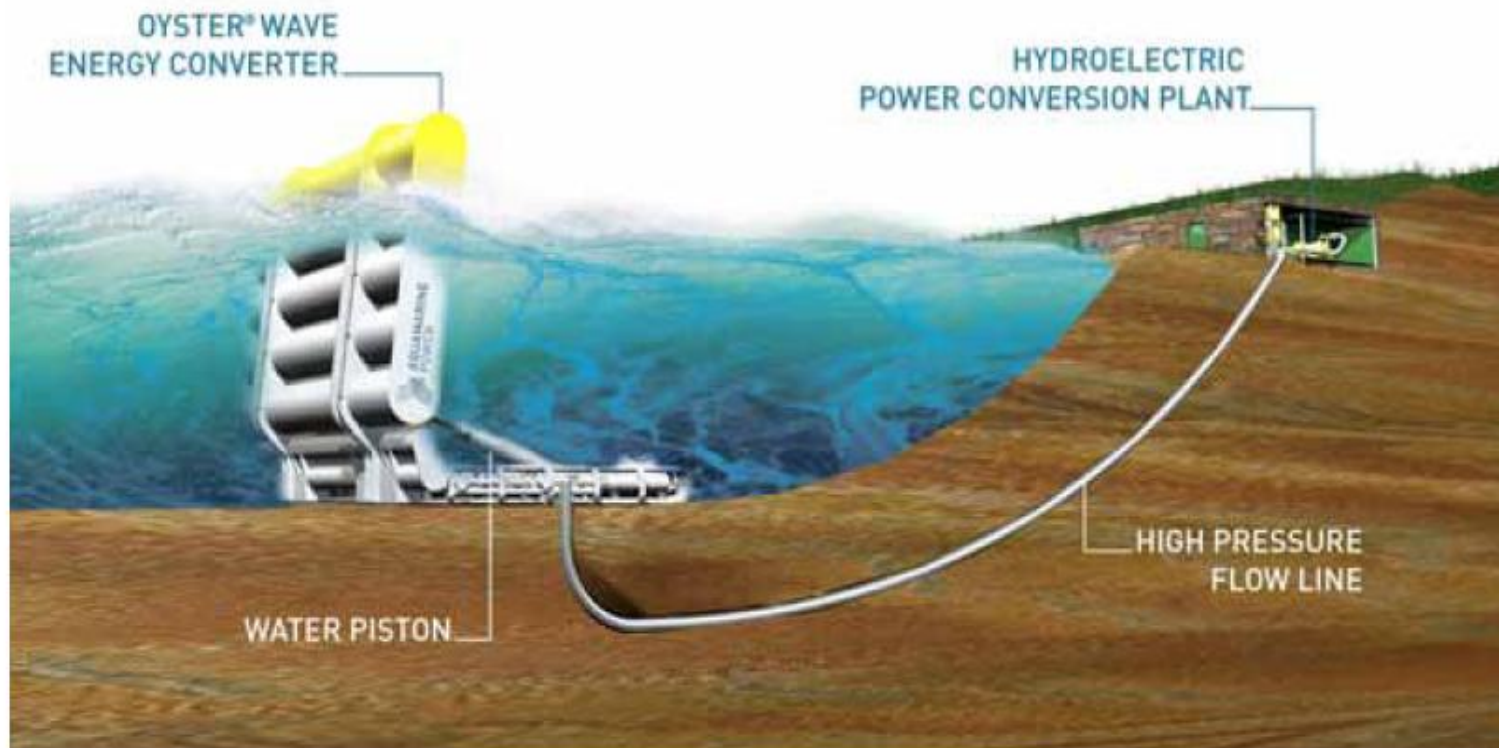


The future ? (CorPower Ocean)



Other examples of Wave-Swell systems

Figure 19 The Oyster system from Aquamarine Power uses a buoyant hinged flap to capture wave energy and pump water through a directionally-drilled pipe to an onshore-generator. Several flaps could be used to pump water to one generator



Picture from Aquamarine Power



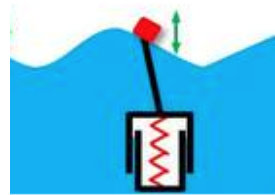
Different types of Wave Energy Converter (WEC)



WEC (Wave Energy Converters) : the main solutions



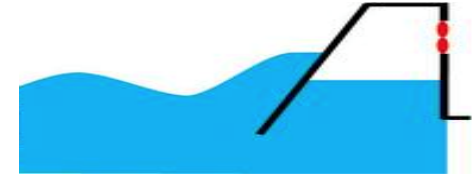
1) Attenuator



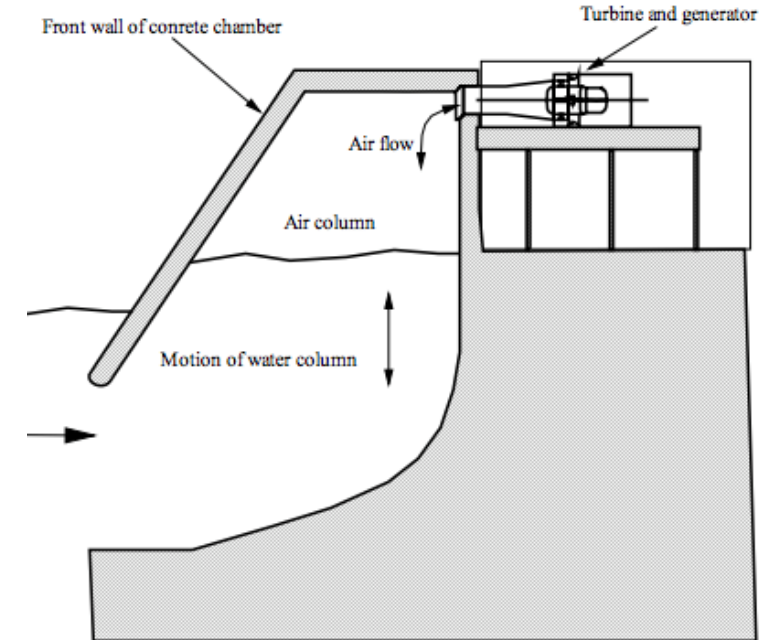
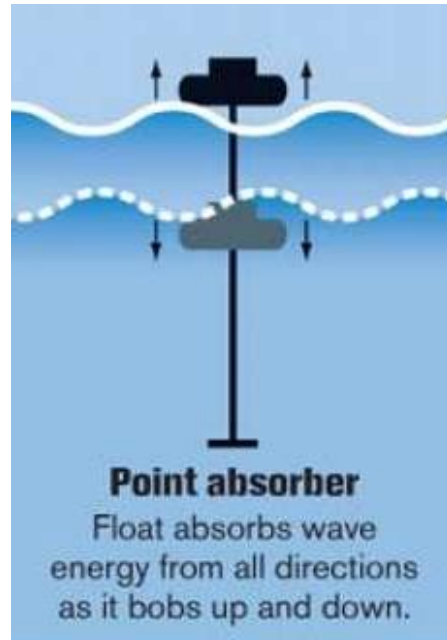
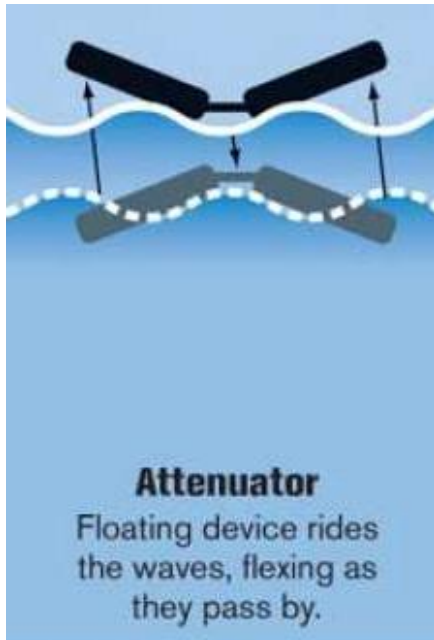
2) Absorber



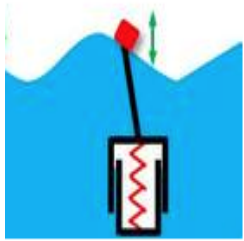
3) Hydraulic Flapping



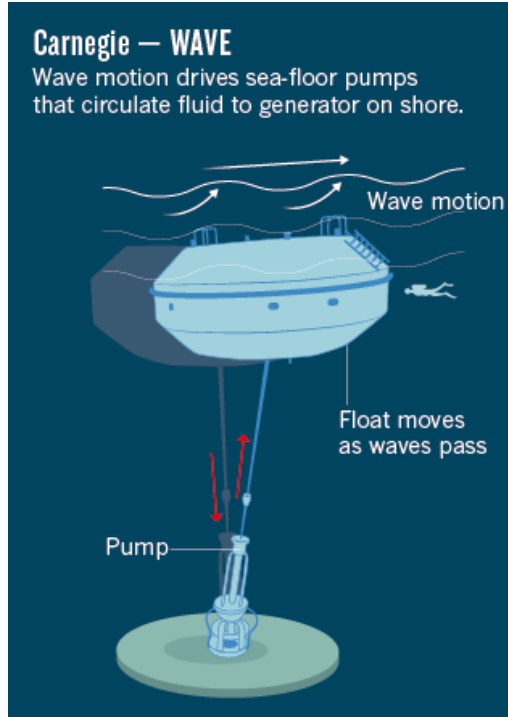
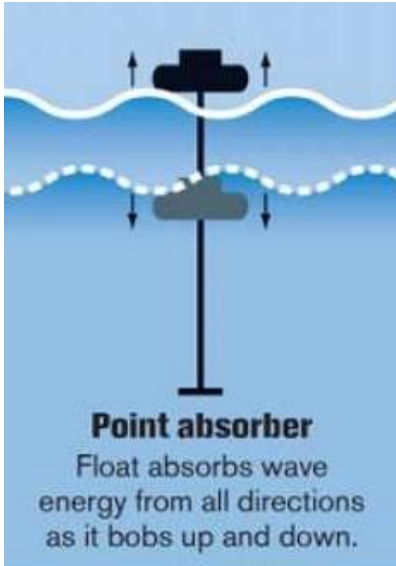
4) Oscillating water column



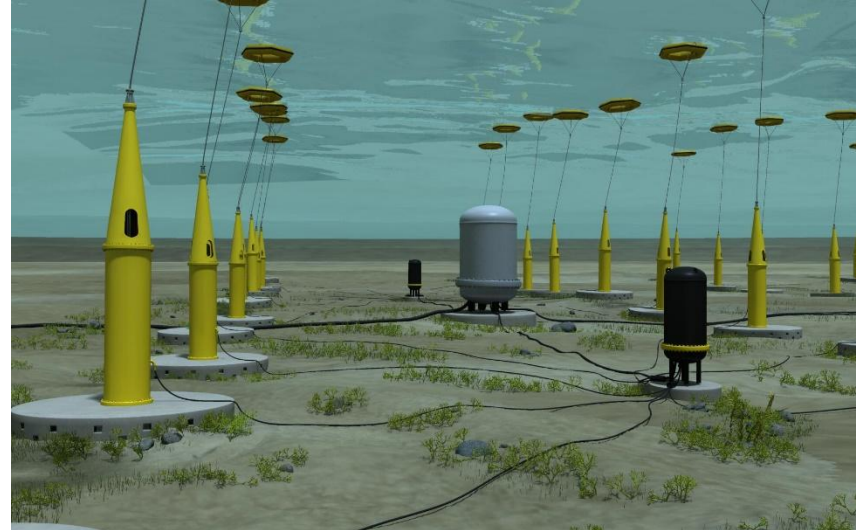
WEC 2 : Absorber



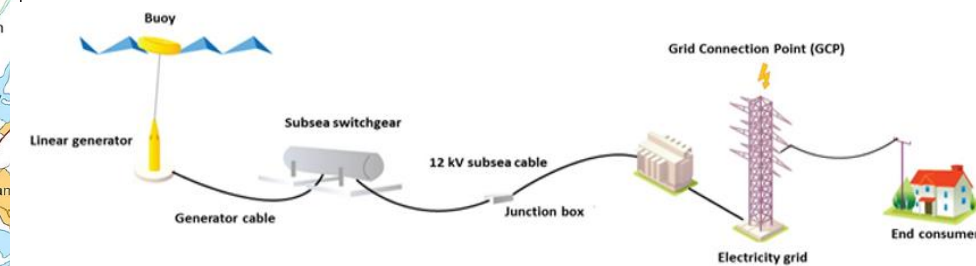
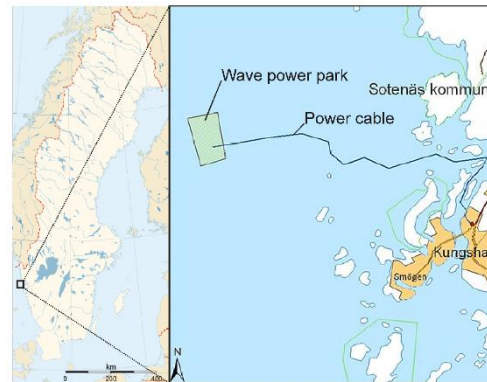
2) Absorber



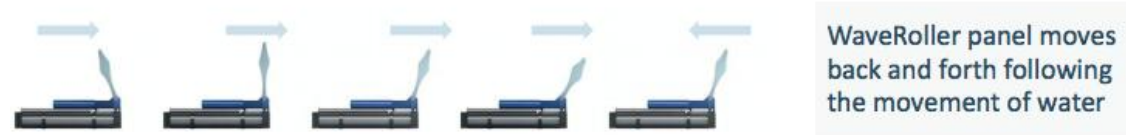
Electricity is generated offshore and export to shore by electric cables



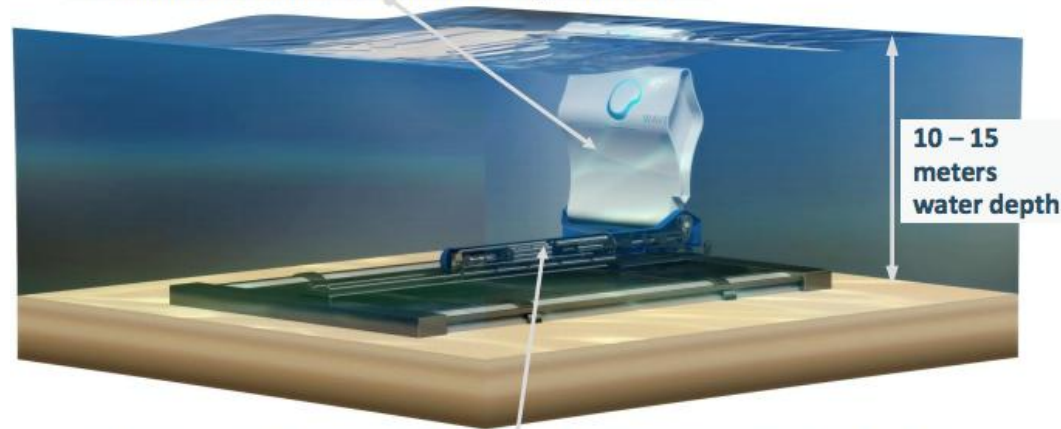
Swedish Seabased 1,05MW Sotenäs project
(in operations since 2015)



WEC 3 : Hydraulic flapping



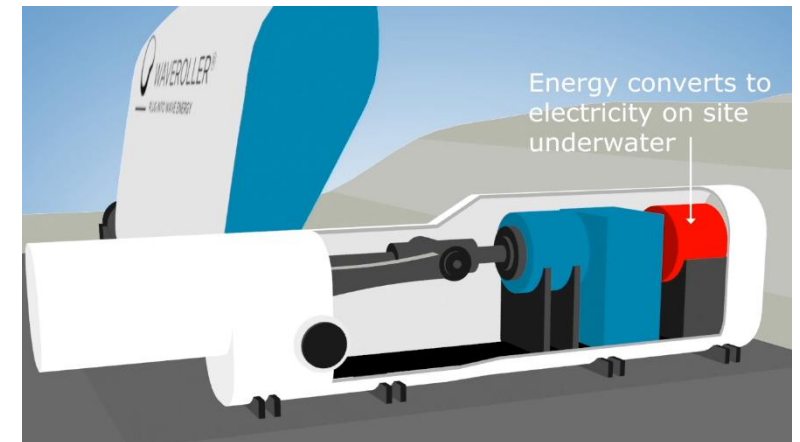
Panel moves back-and-forth following the waves



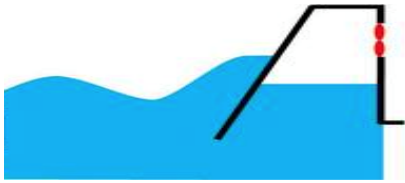
Power take-off converts the back-and-forth movement to electricity



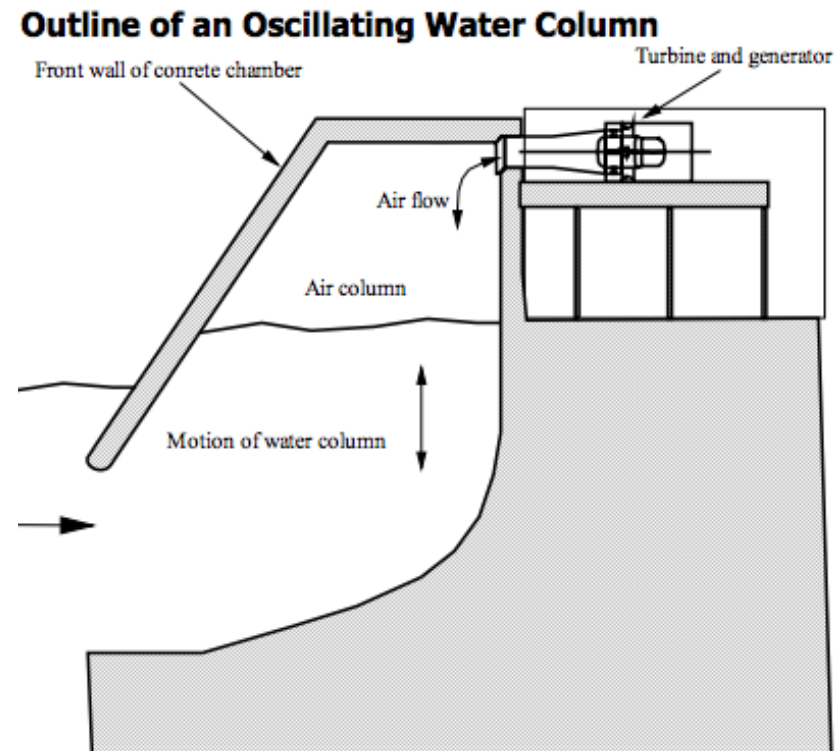
3) Hydraulic Flapping



WEC 4 : Oscillating water column



4) Oscillating water column



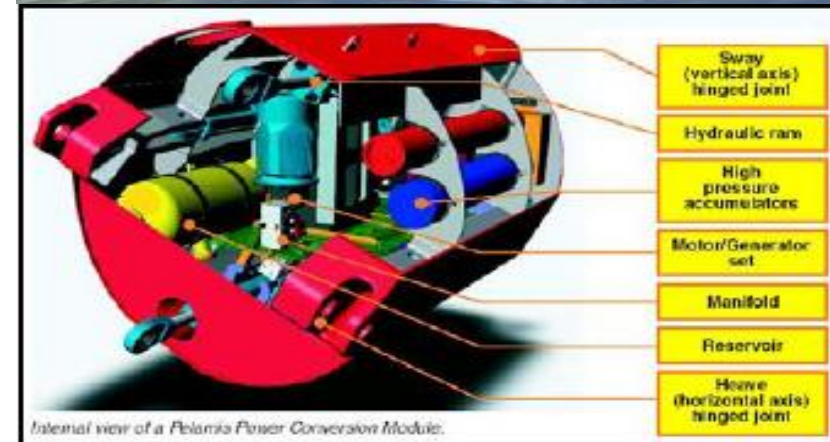
**The company Pelamis Wave Power (Scotland)
ceased to exist in 2014**



The Pelamis System

Pelamis Wave System (ex Ocean Power Delivery Ltd)

Company	Ocean Power Delivery Ltd (Norsk Hydro Ventures is one shareholder)
Location	EMEC Orkney
System type	Wave activated bodies Offshore
Water Depth	50-60 m
Unit Size	130 m long 3.5 m de diameter 700 T (400 T ballast)
Power	750 kW/unit 30 MW/km2
Capacity rating	Offshore windmills ISO



Pelamis Internals



Source: Pelamis Wave Power

550

TPA Toolbox Energy Book 7 – Renewables

E-ON's Pelamis P2 at EMEC – April 2012

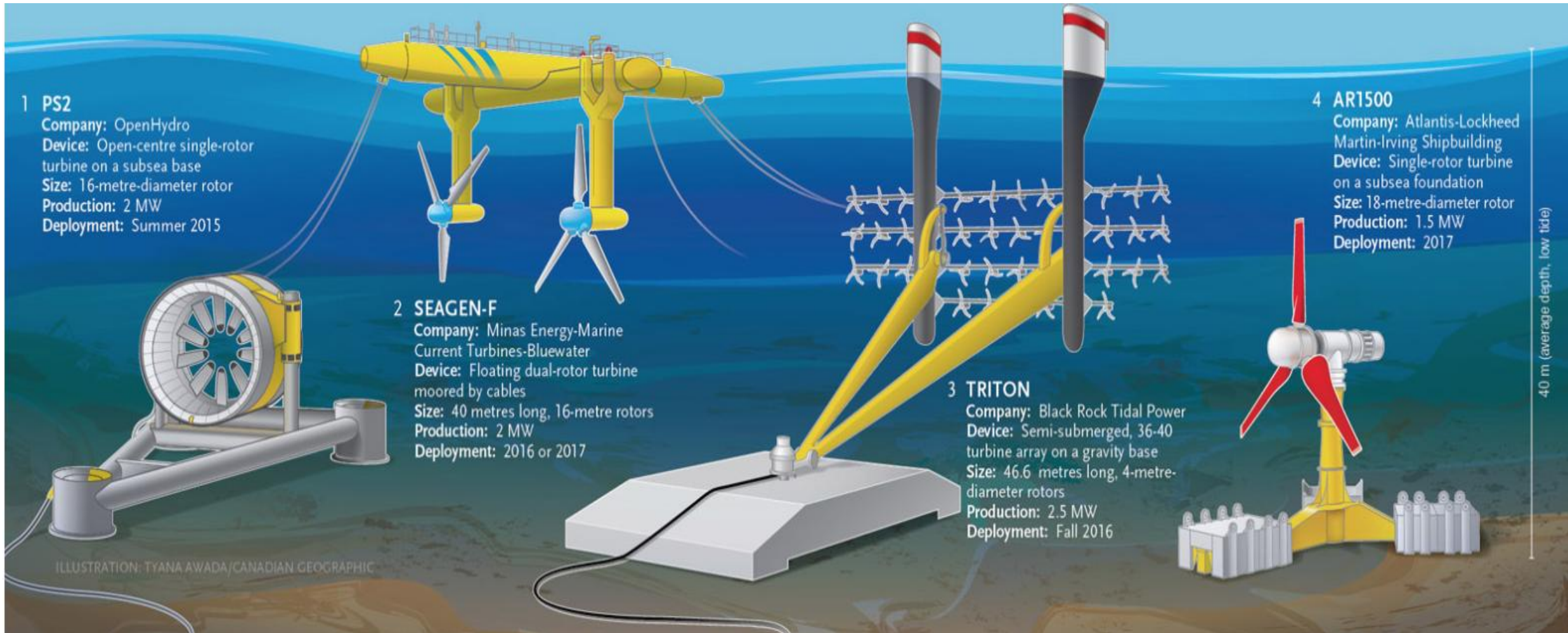


6-5

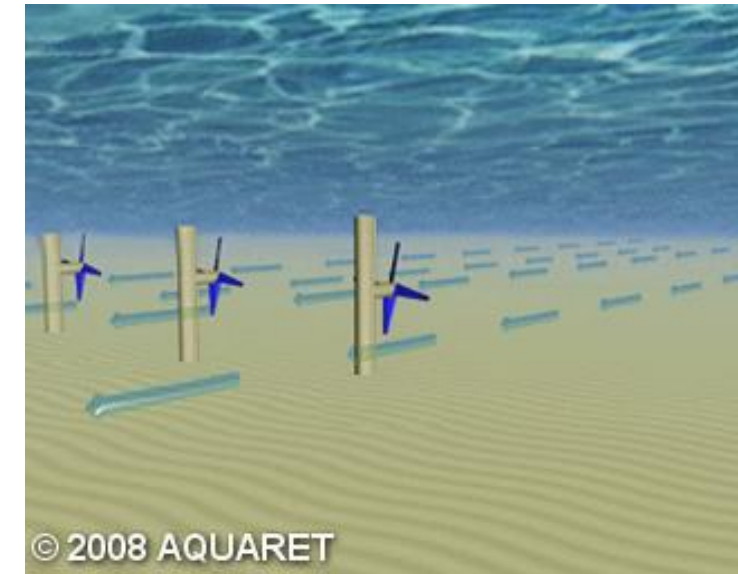
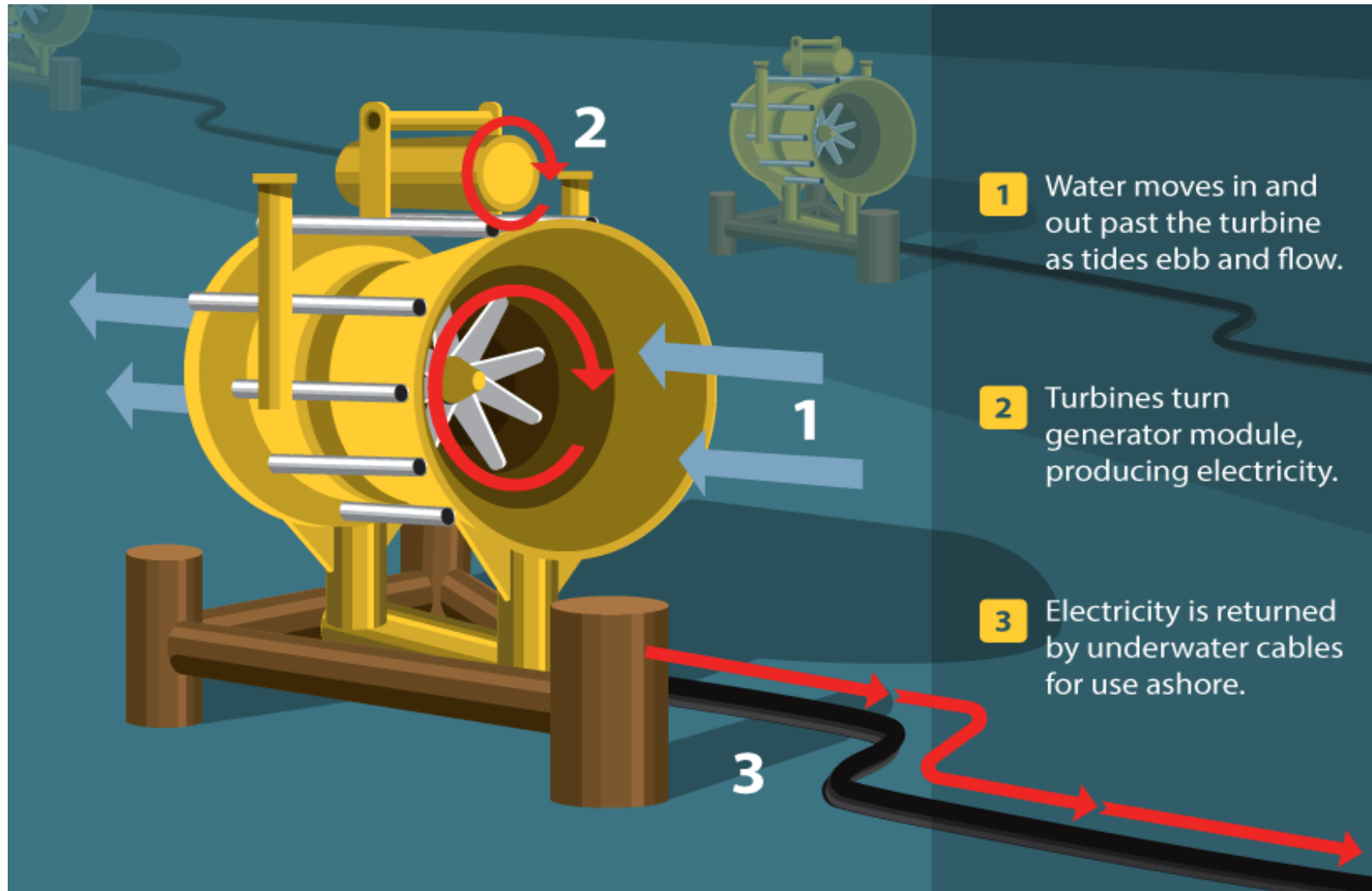
Current Forces Energy



Various concept using current forces

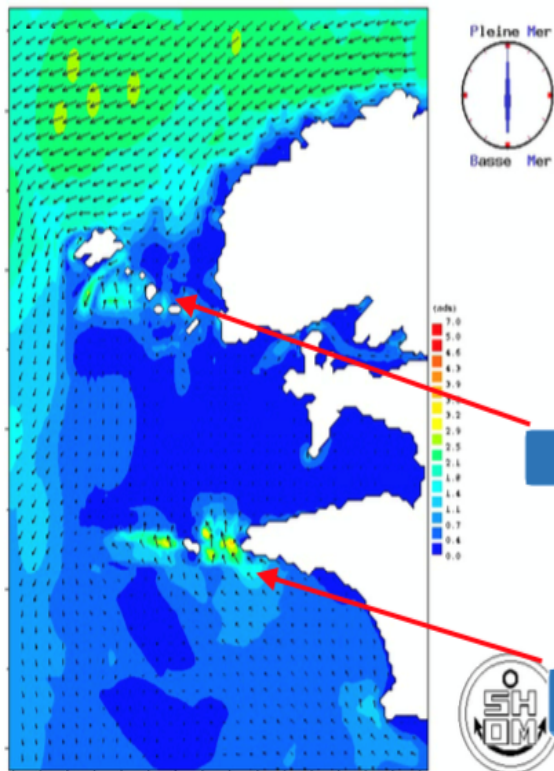


How an Hydrolienne works



France potential

Courants de marée en mer d'Iroise
(Référéncés par rapport à Brest)



Conjonctions de la ressource :
sites de forçage en zone de fort marnage.

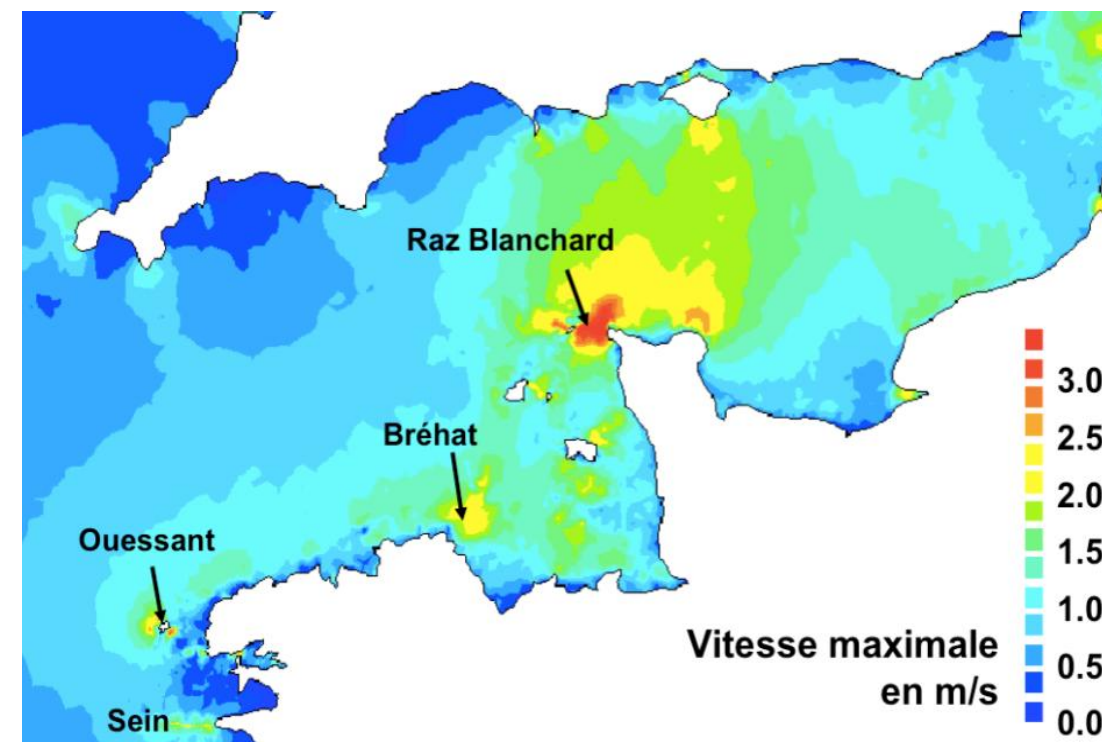
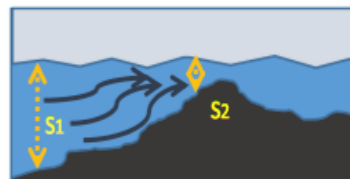
Topographie

Détroit, passe, cap,
presqu'île, isthme, etc.

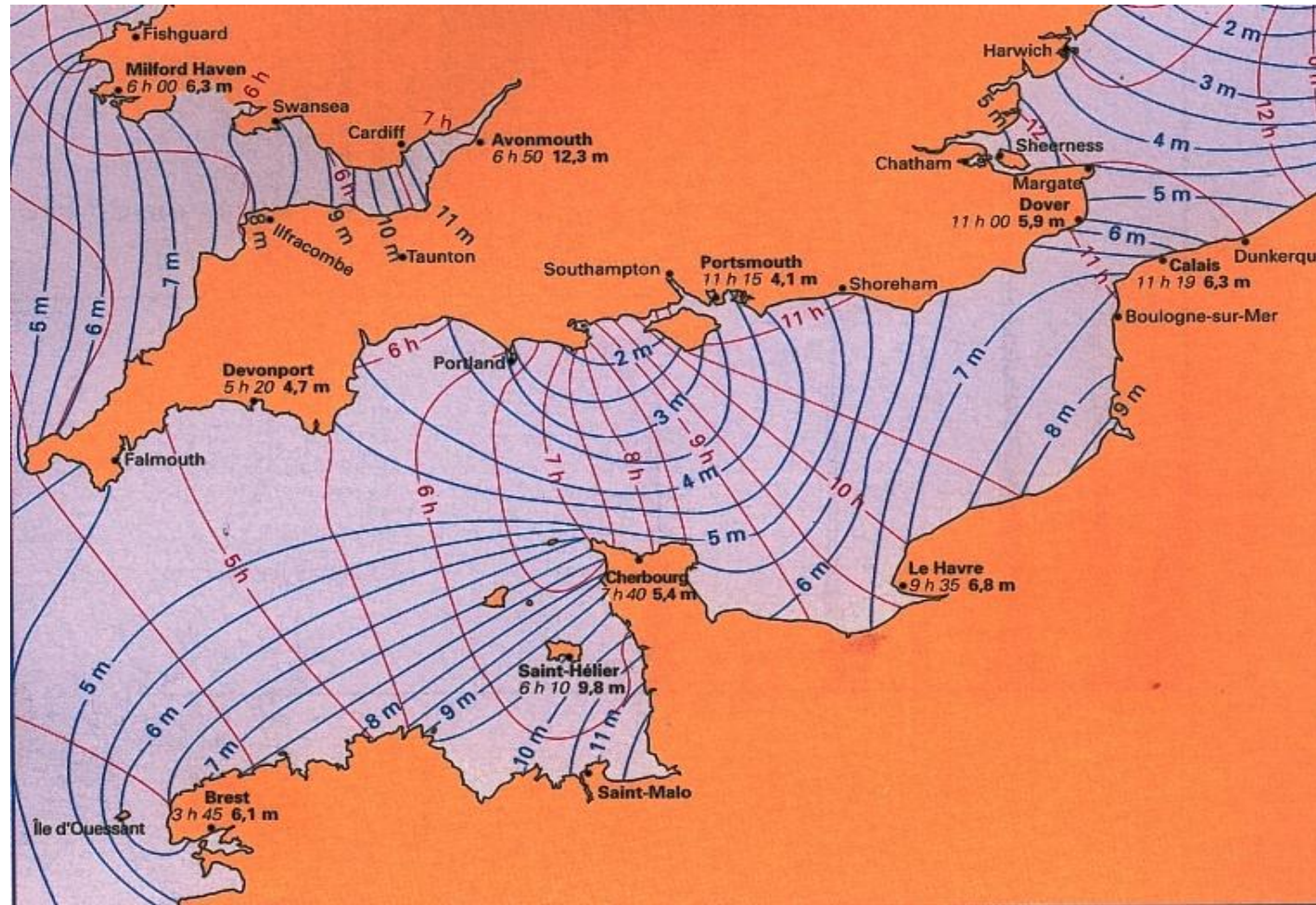


Bathymétrie

Dune sous marine, haut
fond, plateau, etc.



Cotentin / Finistère: Time phasing in the France / UK channel

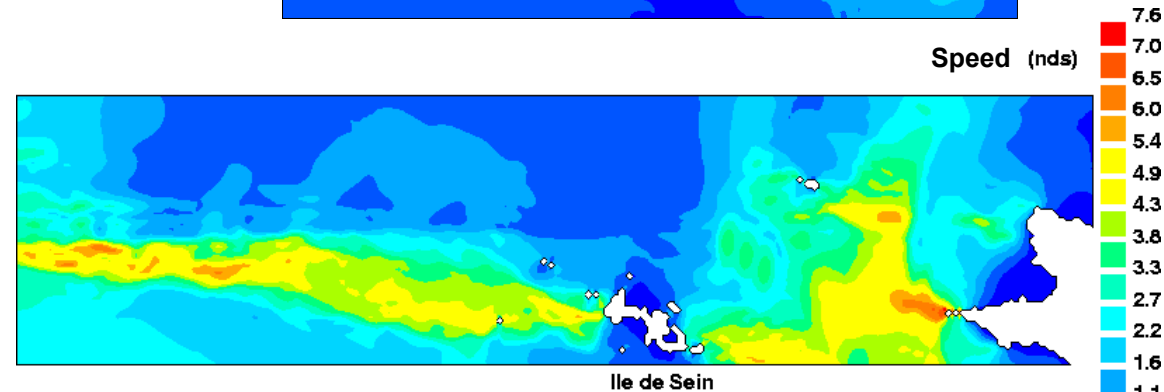
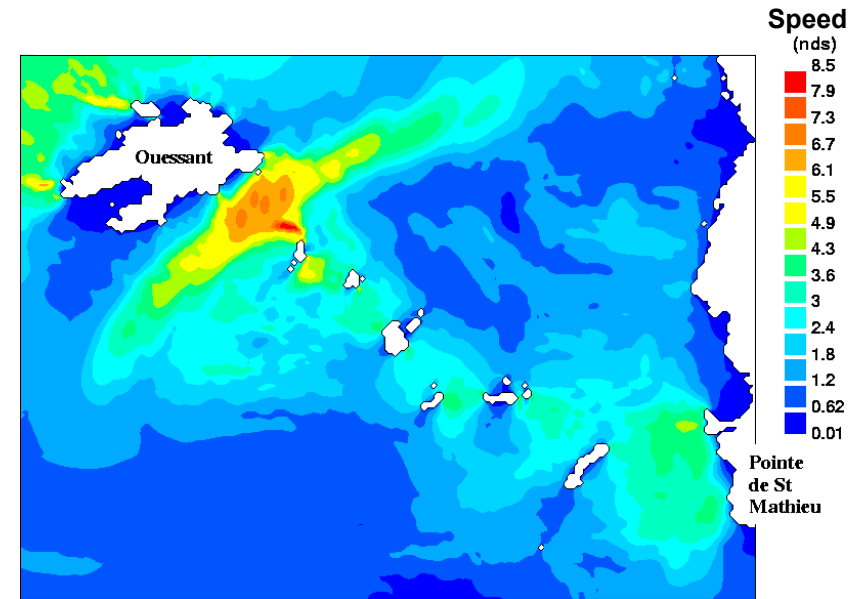
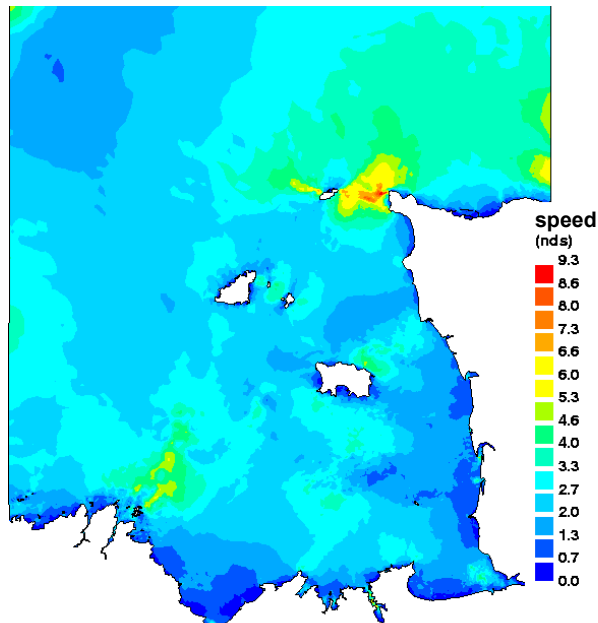


Highly complex modelling for future design of sea current underwater mills



An example: the three largest potential sites in France for Sea Currents Power

Chaussée et Raz de Sein :	1000 MW
Fromveur (Ouessant) :	2000 MW
Raz Blanchard :	3000 MW
Total	6000 MW



Maximum current speeds in average water regime

Akuo/Sabella : PHARES Project in Ouessant



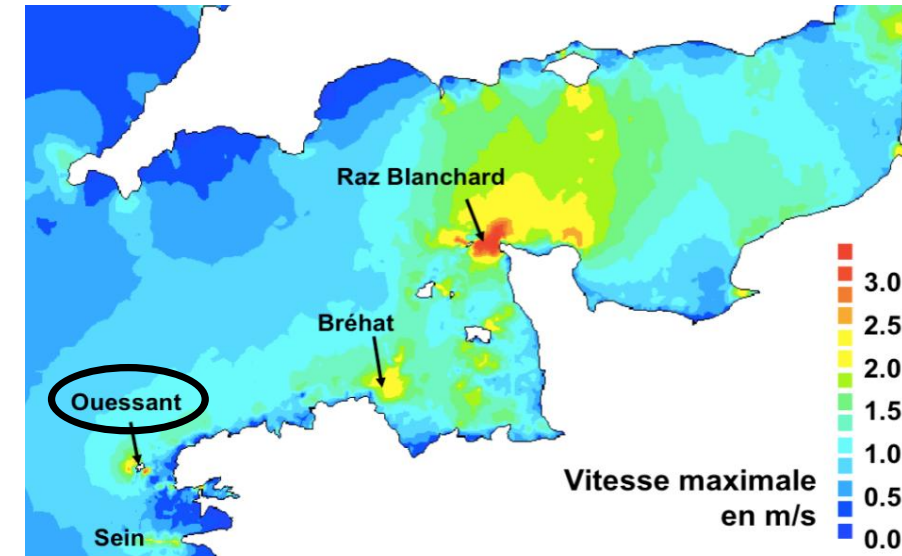
UN NOUVEAU MODÈLE ÉNERGETIQUE INSULAIRE

Tests
2015-2019
Sabella D10 - 1000
Power 1MW
400 tons
Fromveur-Ouessant
WD=55m

PHARES

Après avoir validé en 2015 l'opérabilité de son hydrolienne D10-1000 dans le passage du Fromveur, SABELLA s'attelle au projet PHARES qui sera mis en service en 2022.

Ce projet, porté par AKUO Energy, se compose de deux hydroliennes (2 x 500 kW), d'une éolienne (900 kW), de panneaux solaires (500 kW) et d'un système de stockage de l'énergie innovant. Il couvrira près de 80% des besoins électriques de l'île de Ouessant, économisant 1,5 million de litres de diesel par an.



6-6

New Innovation - New concepts Dragon 12 by Minesto (Swedish company)



The Dragon 12 concept – Developed by Minesto (Sweden)



Powerful, lightweight and modular power plants.

With an outstanding power-to-weight ratio, our kite systems can operate cost-effectively, enabling affordable energy from the ocean.

Rated power of	100 kW – 1.2 MW
----------------	-----------------

Weight	2.7–28 tonnes
--------	---------------

Wing span	4.9–12 m
-----------	----------



The Dragon 12 concept – Developed by Minesto (Sweden)

Imagine you are standing on a beach flying a kite in the wind. You feel the strong lift force from the kite in the rope as the wind tries to carry the kite away. As you move the kite sideways, you notice that it flies fast.

If you would attach a turbine to the kite and put it in the ocean, where a water current flows instead of the wind blowing, you would have the concept of Minesto's patent and awarded marine energy technology.

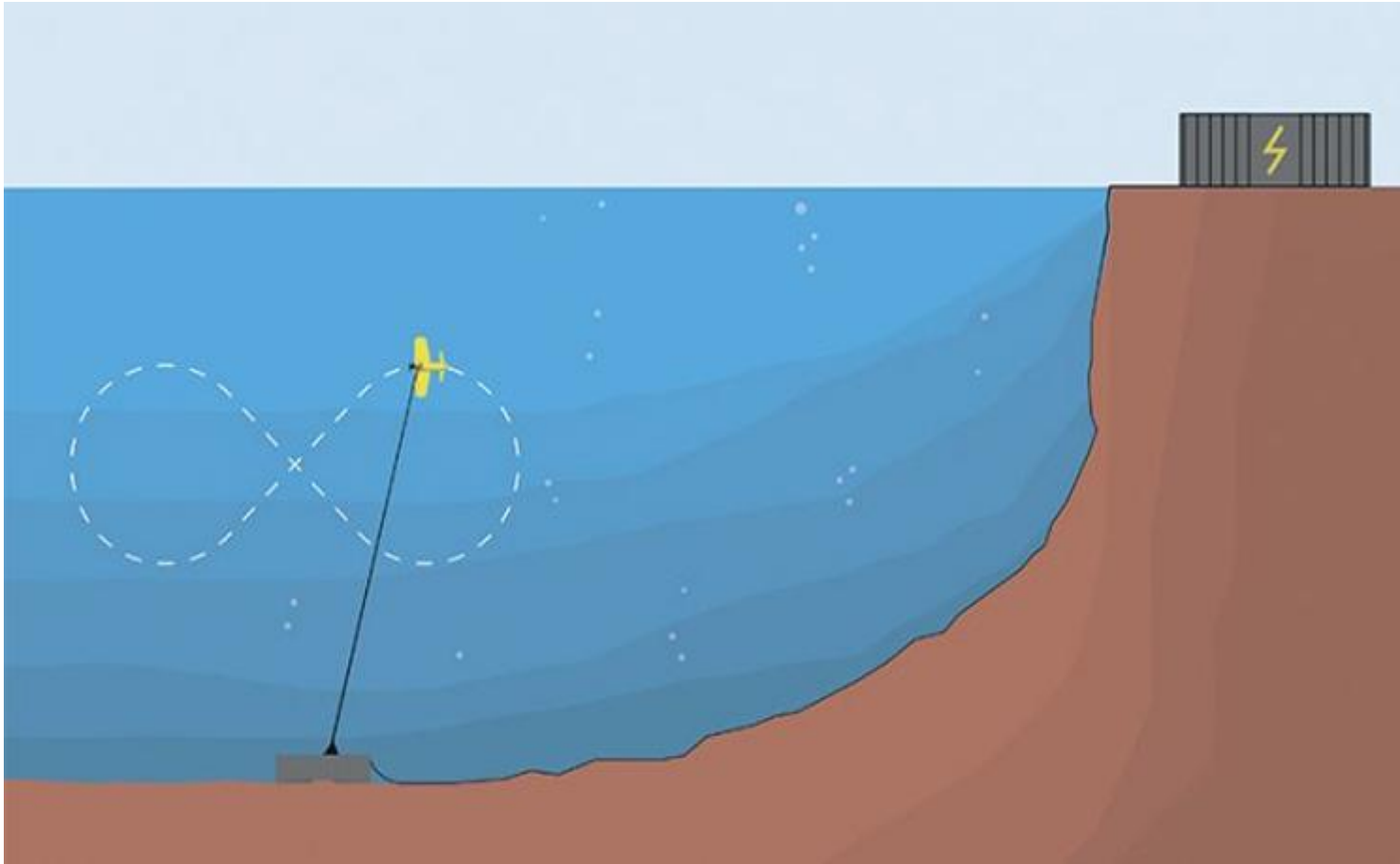
Featuring increased performance and decreased manufacturing costs, the Dragon Class is a new range of power plants. It evolves from the grid-connected Deep Green systems Minesto has installed and operated in Vestmannastrandur, Faroe Islands (Kingdom of Denmark)

What makes the Deep Green technology different from other tidal energy technologies is the wing, the size of the turbine and the fact that the power plant is “flying” under water.

The wing pushes the turbine through the water in an eight-shaped trajectory, sweeping a large area at a relative speed that is several times the actual speed of the underwater current. The speed has a cubic relationship to the power production. This means that when a Deep Green power plant multiplies the relative speed which the turbine is pushed through the water, the electricity produced by the generator is several hundred times greater compared to if the turbine would be stationary.



The Dragon 12 concept – Developed by Minesto



What makes the Deep Green technology different from other tidal energy technologies is the wing, the size of the turbine and the fact that the power plant is “flying” under water. The wing pushes the turbine through the water in an eight-shaped trajectory, sweeping a large area at a relative speed that is several times the actual speed of the underwater current.

Source: JEC Group – Minesto 2025

The Dragon 12 concept – Developed by Minesto



Source: JEC Group – Minesto 2025 – Offshore Energy

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TPA Toolbox Energy Book 7 – Renewables

The Dragon 12 concept – Developed by Minesto



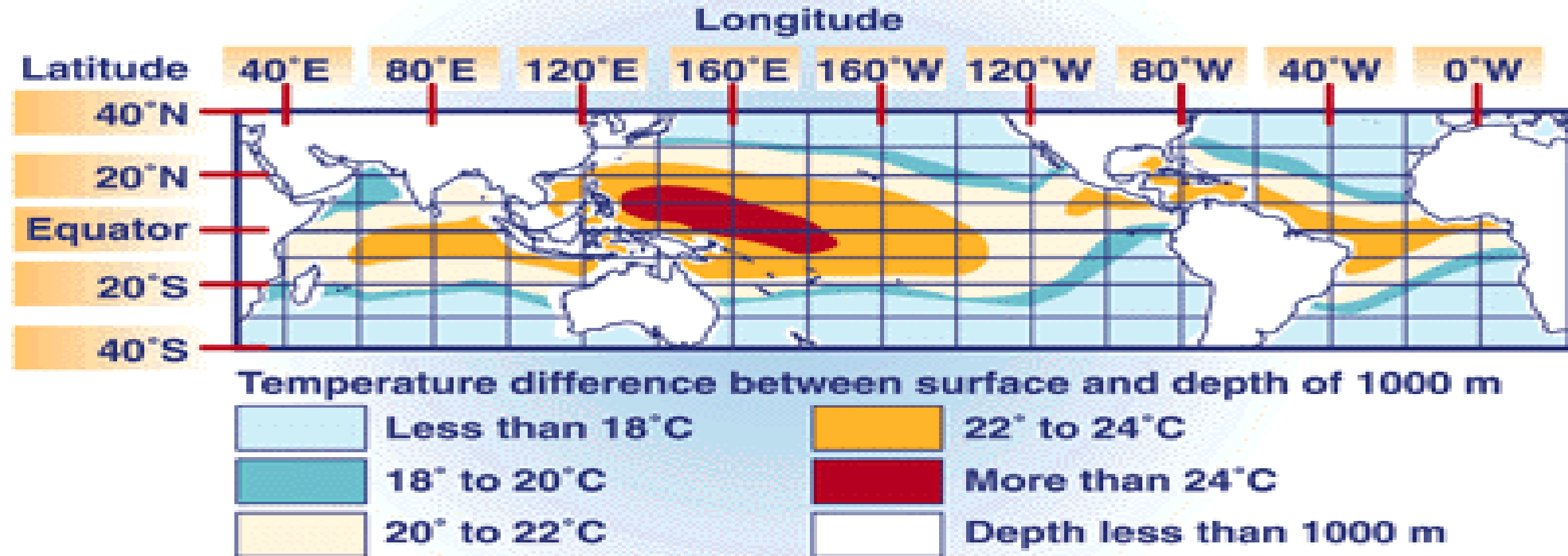
6-7

Ocean Thermal Energy Conversion (OTEC)



Ocean Thermal Energy Conversion (OTEC)

Energie hydrothermique des mers (ETM)



Ocean Thermal Energy is produced by using the ocean thermal gradient between cooler deep and warmer shallow or surface seawaters.



OTEC closed cycle method

(2016- Mines ParisTech)

OTEC cycles generate electricity in tropical areas using the temperature difference between surface (26-28°C) and depth (around 4-6°C) below 1000 m.

Surface hot water is used to evaporate a liquid, generally ammonia, boiling at low temperature.

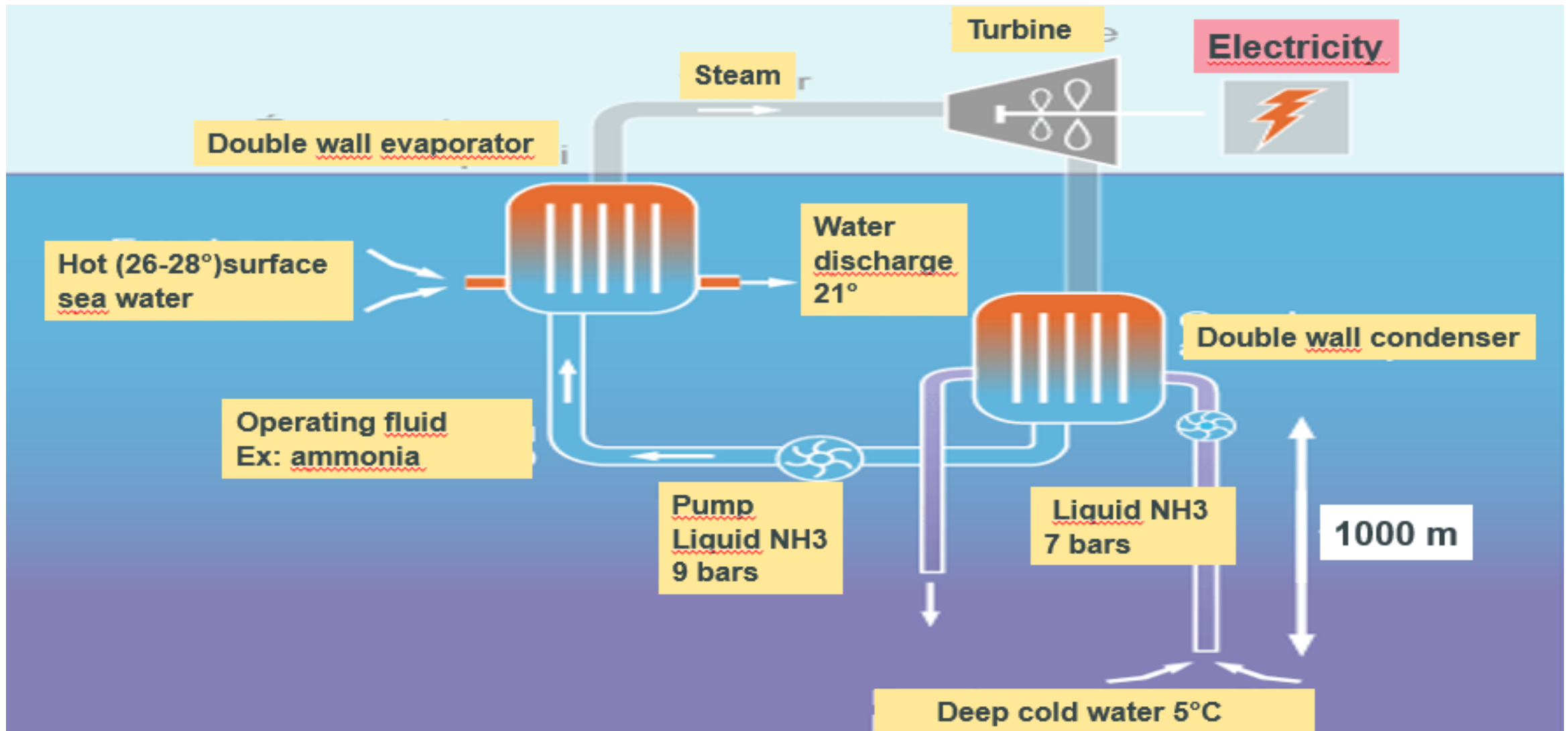
- **Ammonia boiling temperature at atmospheric pressure : -33°C**
- **Ammonia boiling temperature when compressed at 7 bars : + 12°C**
- **Ammonia boiling temperature when compressed at 9 bars : +21,5 °C**

The ammonia steam drives a turbine generating electricity and is then condensed by cooling in a condenser using cold water pumped from the depth. The cycle repeats.

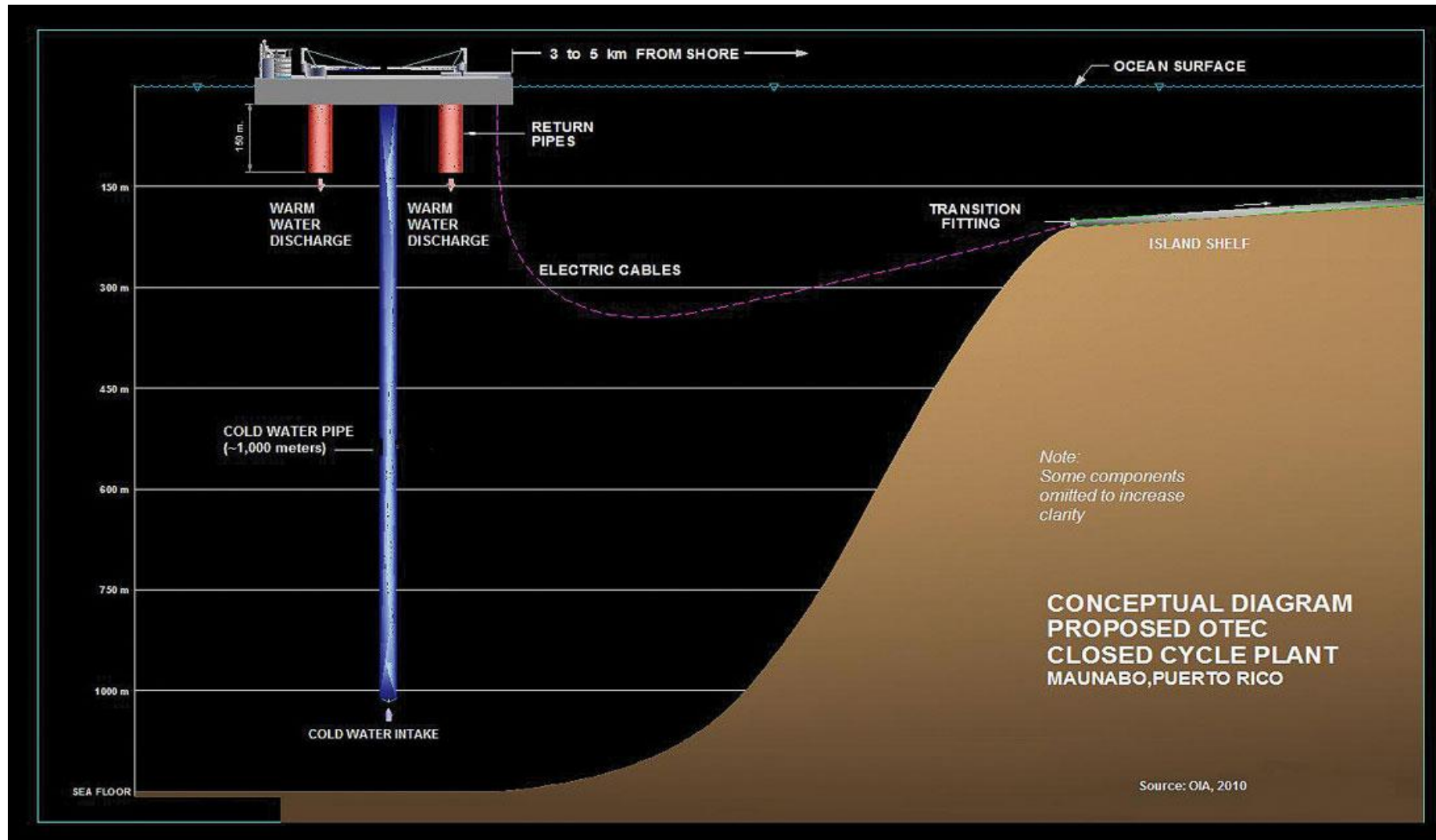
In any case , it is necessary to use large volume of fluids and to pump cold water from great depths. The process has therefore to be carefully optimized.



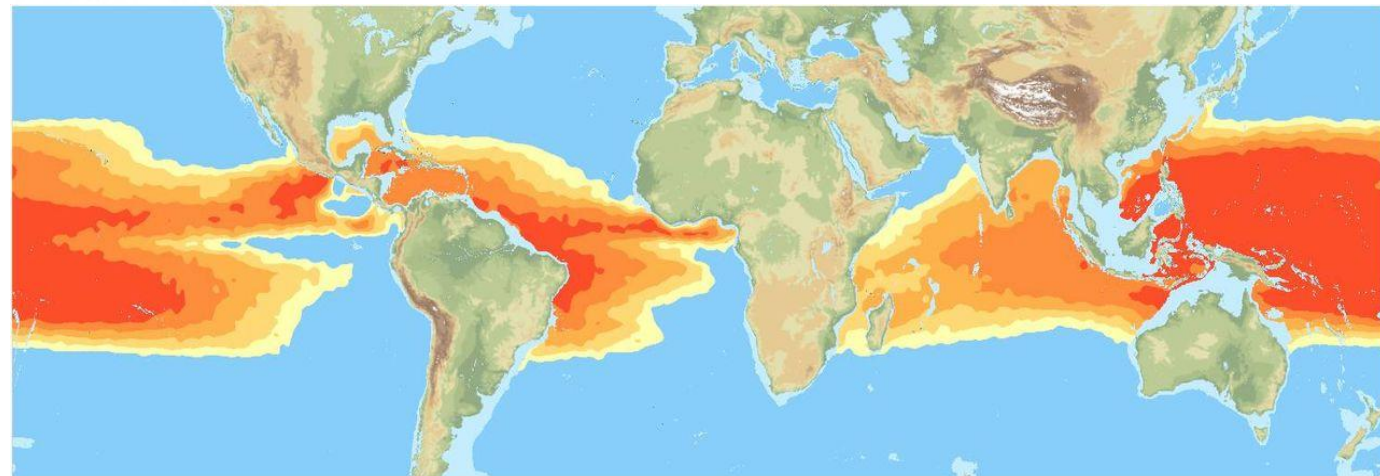
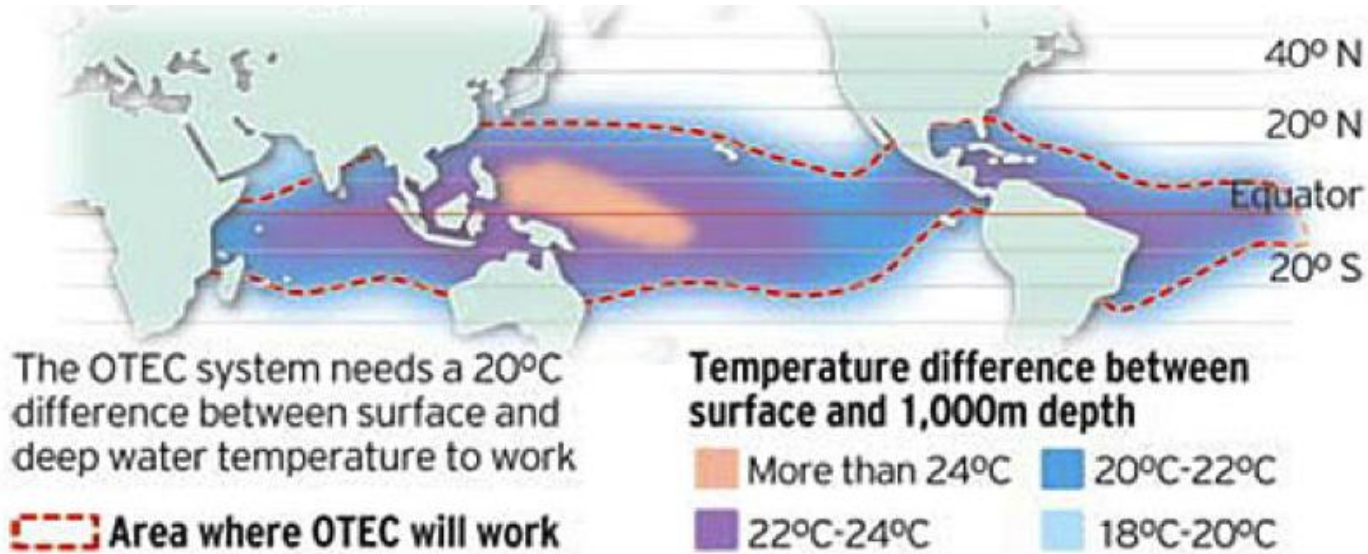
OTEC closed cycle



The concept



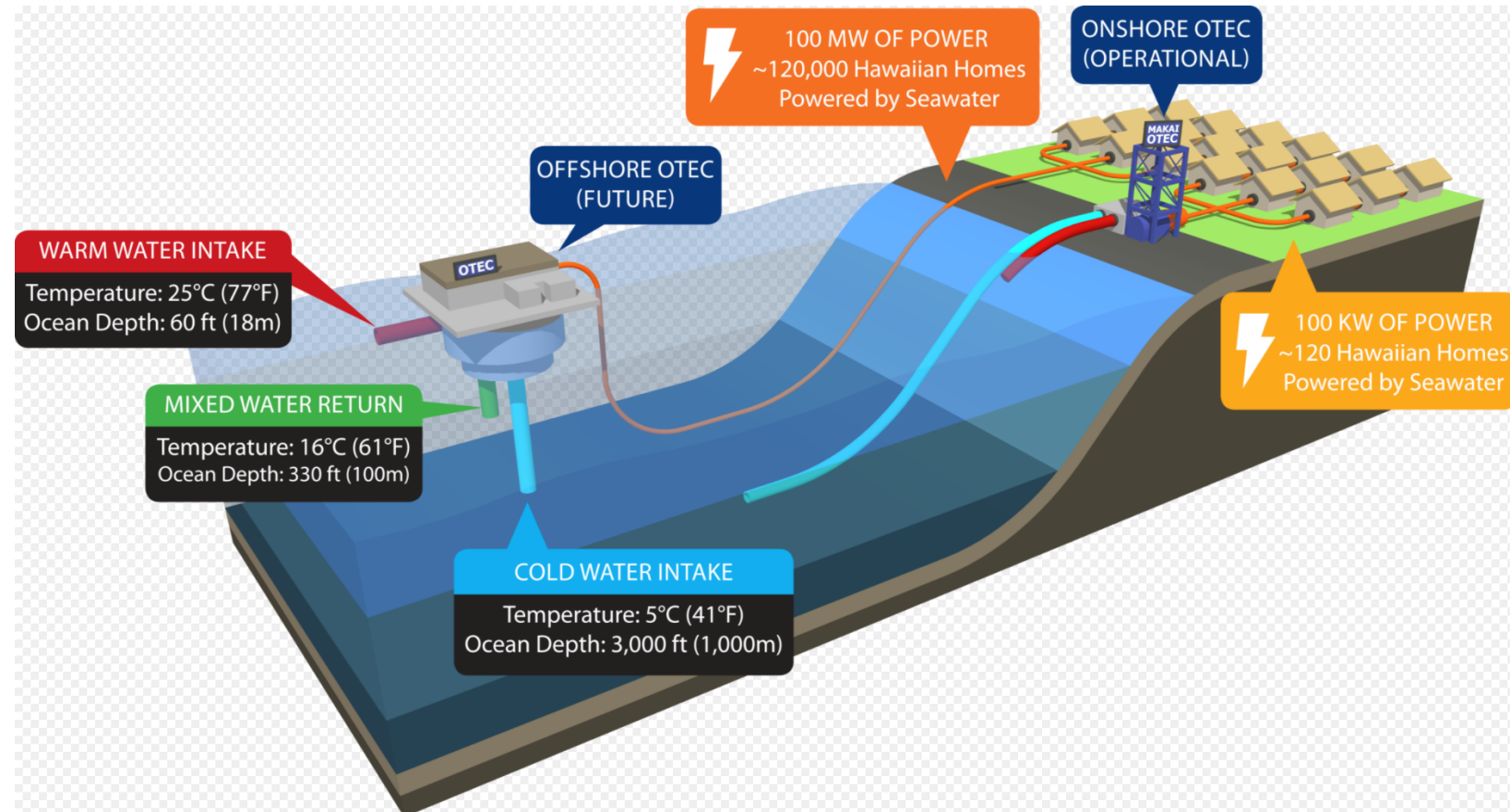
Where OTEC could work



OTEC Test Facility : Makai Ocean Engineering (Hawaii)

The world's largest operational Ocean Thermal Energy Conversion (OTEC) power plant

- In operations : 2015
- WD = circa 1 000 m
- Delta Temperature = 20°C
- Availability 24H/24H 365 days/year
- 100 KW for 120 homes



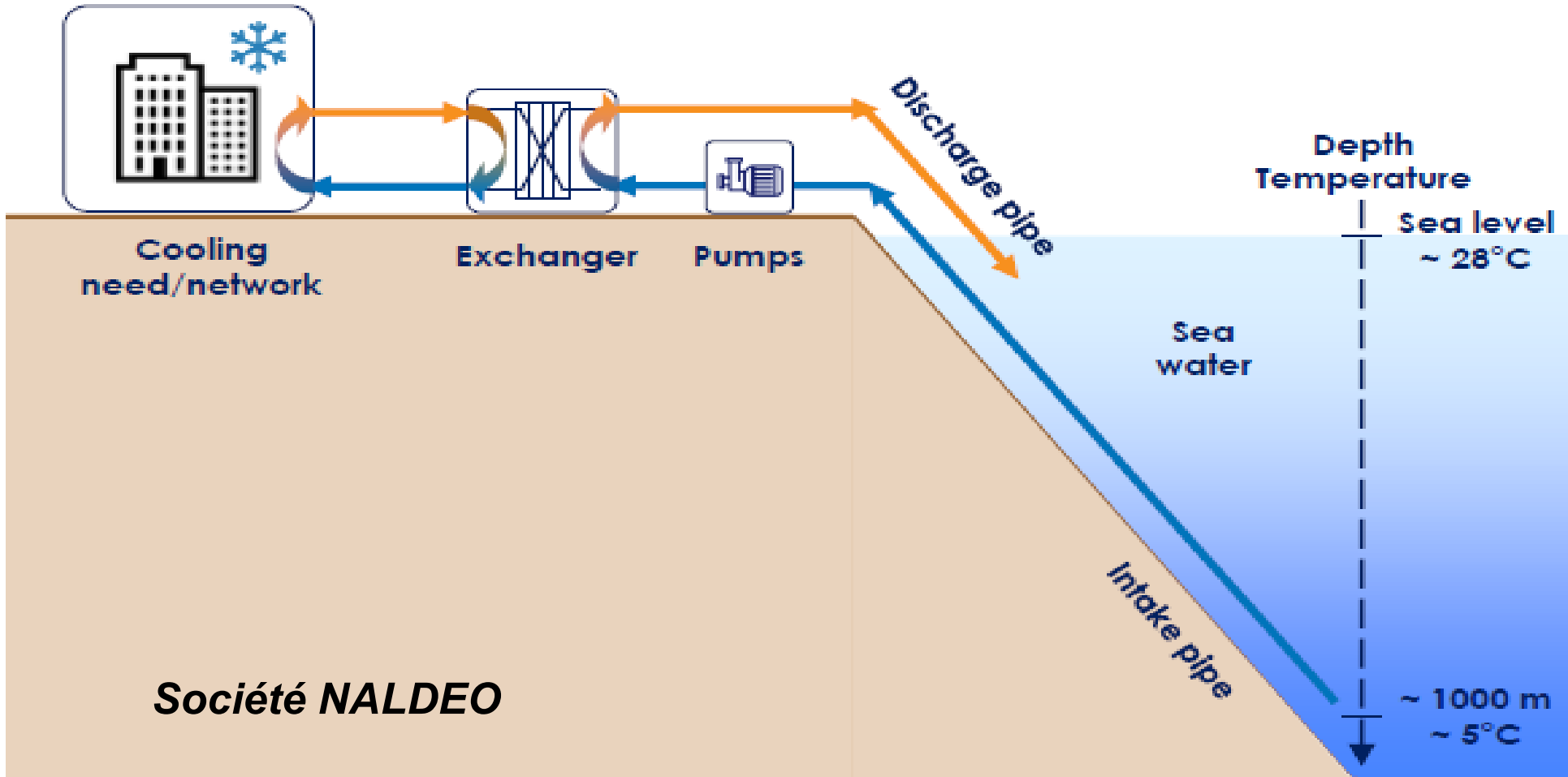
6-8

Sea Water Air Conditionning (SWAC)



Sea Water Air Conditionning (SWAC)

Concept of the method



Sea Water Air Conditionning (SWAC)

« Le SWAC permet, à très faible consommation énergétique, de mettre en contact thermique l'eau de mer froide et l'eau douce du réseau de climatisation, au travers d'un millefeuille de plaques en titane. Ce système d'échanges ne nécessite pas de mélange des eaux : l'eau de mer, après avoir transmis ses frigories [unité de mesure de la quantité de froid], est rejetée dans l'océan sans avoir été altérée. »

David Wary, ingénieur de la société Airaro, Polynésie française. « le Monde » 7 novembre 2021



SWAC air conditioning system of the French Polynesia regional hospital (Tahiti)

The SWAC air conditioning system of the Pirae hospital (North of Tahiti) was completed in February 2022 .

SWAC pumps have a flow rate of 1000 m³ per hour of water drawn from the Pacific Ocean at a depth of 900 meters and a temperature of 5°C.

The hospital will not use any more electricity to generate cold (with potential savings of 9 millions Kwh per year) by linking the air conditioning system to a subsea pipe 3,8 km long.

Which means a savings of 2,5 millions euros per year and a 2 % reduction of Tahiti electric needs.

But for a significant investment (31 millions euros)

Le Monde - 7 novembre 2021



Le SWAC du Centre hospitalier de Polynésie française

Le réseau de climatisation du centre hospitalier de la Polynésie française situé à Pirae, au nord de Tahiti a été terminé fin 2021 C'est désormais une énergie renouvelable qui refroidira l'hôpital.

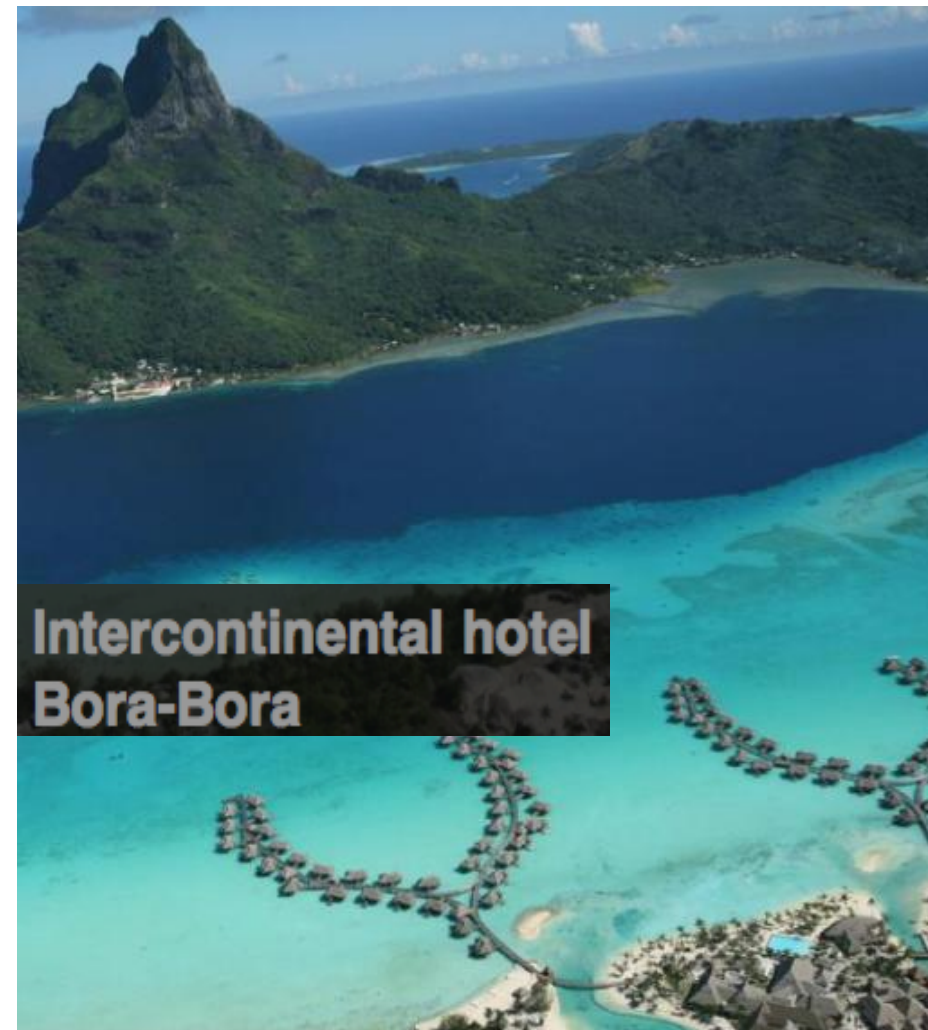
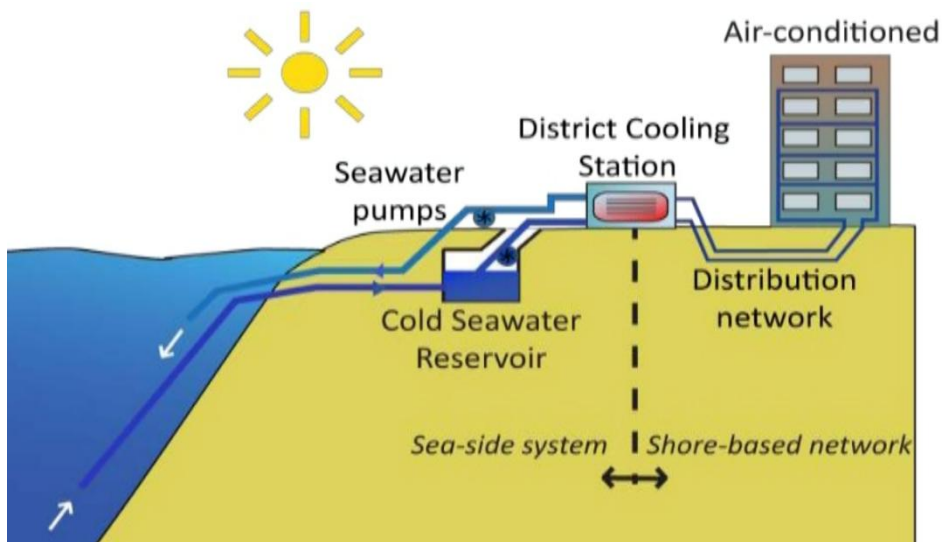
Les pompes du SWAC puiseront un million de litres à l'heure d'eau à 5°C, à plus de 900 mètres de profondeur dans l'océan Pacifique. L'hôpital n'utilisera plus d'électricité pour produire du froid (économie de 9 millions de Kwh) en reliant son système de climatisation à une canalisation sous-marine de 3,8 km de long,

Ceci permettra une économie de 2,5 millions d'euros par an et une réduction de 2 % des besoins électriques de Tahiti, mais pour un investissement lourd (31 millions d'euros).

Le Monde du 7 novembre 2021



1st SWAC : Intercontinental Hotel in Bora-Bora



2nd SWAC : Tetiaroa Hotel Moskito Island



Water depth = 960 m
Pipe length = 2 km
Pipe HDPE dia = 120 mm



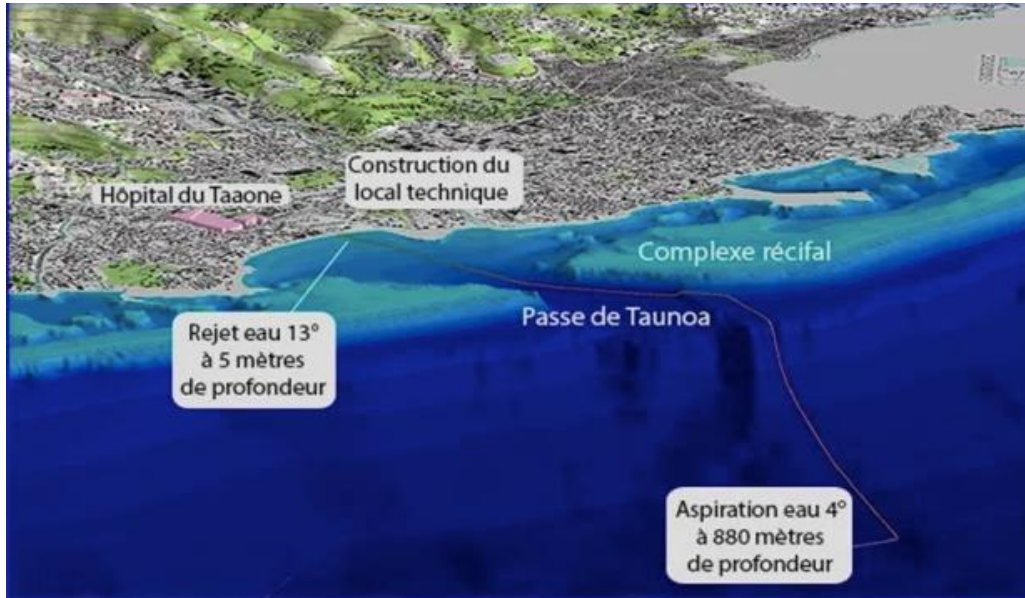
Richard Branson
RÉFUGIÉ CLIMATIQUE

LE MILLIARDAIRE
A VU SON ÎLE RAVAGÉE PAR
L'OURAGAN IRMA.
VENU AU SOMMET DE
PARIS, IL BOUILLONNE
D'IDÉES POUR
SAUVER LA PLANÈTE

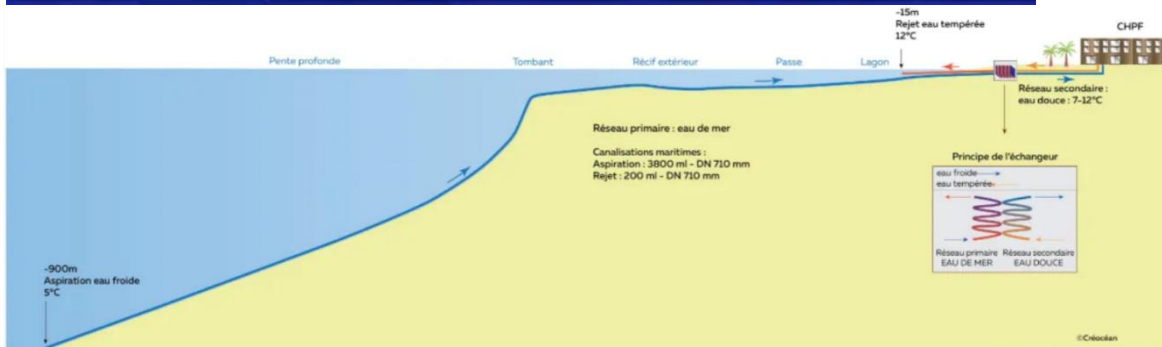
Cette occasion de tenir la sommets d'alarme. Il ne fa pas
lâchée passer. Très mobilisé pour la reconstruction de la
région, le patron de Virgin fait de la destruction de son
paradis tropical le catalyseur qui nous concerne tous : « Les
Caribbes sont un exemple des menaces qui pèsent sur le
monde. Dans un avenir proche, la plupart des pays seront
sans doute confrontés à de nouvelles catastrophes natu-
relles causées par le réchauffement climatique ». Lors sa
présence au One Planet Summit organisé par le président
Macron le 12 décembre. A 67 ans, Richard Branson veut
réinventer l'avenir. Caribbeens progresser pour les auto-
trains en littératie, viande végétale. Il ne manque pas de
projets, 16 de fides. Il en faut pour préserver notre Terre !



3rd SWAC: CHFP (Centre Hospitalier de Polynésie Française à Taaone)



Water depth = 900 m
Pipe length = 3,8 km
Pipe HDPE dia = 4"



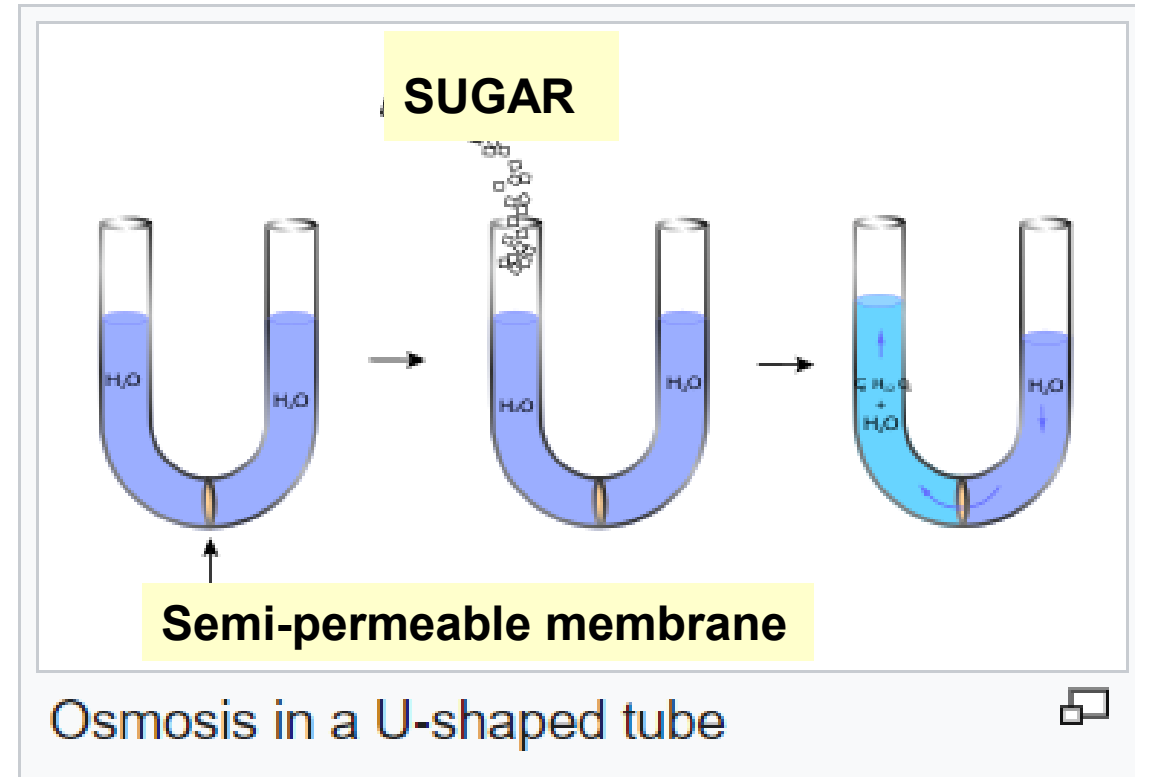
6-9

Osmotic Power



Osmosis phenomenon

Osmosis occurs when two solutions containing different concentrations of solute are separated by a selectively permeable membrane. Solvent molecules pass preferentially through the membrane from the low-concentration solution to the solution with higher solute concentration. The transfer of solvent molecules will continue until equilibrium is attained.

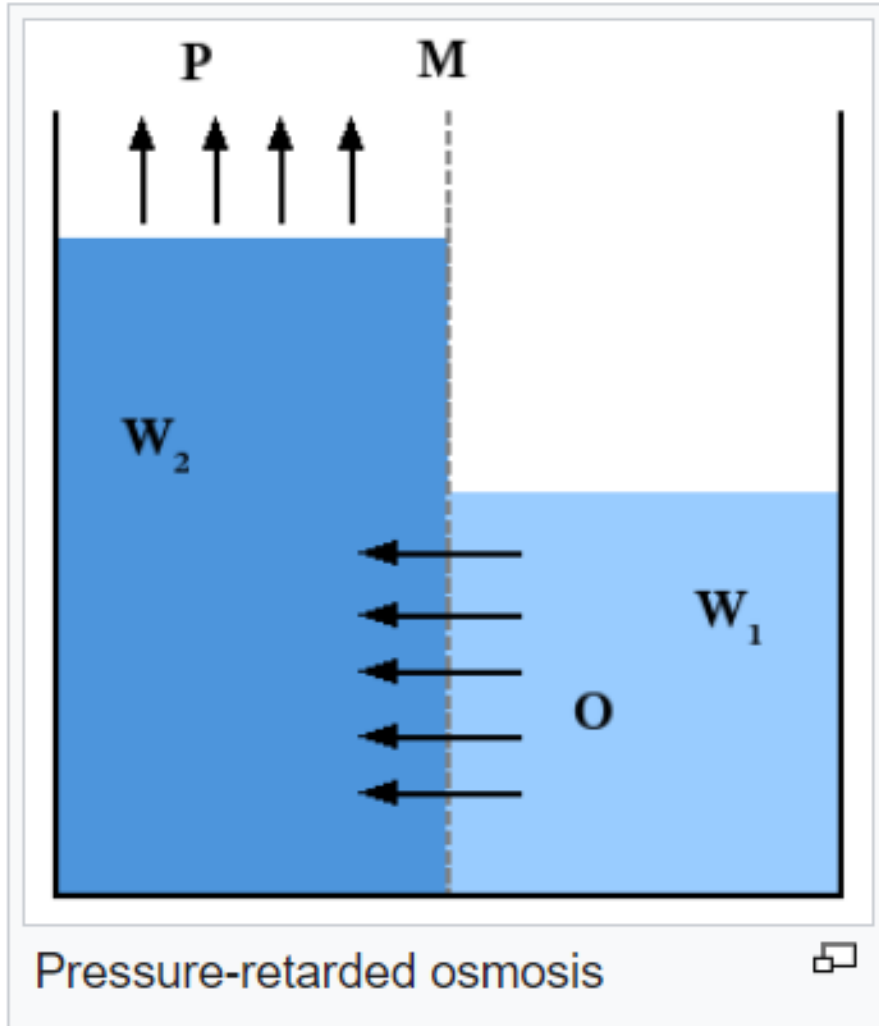


**Isotonic
solution**

**Hypertonic/hypotonic
solutions**



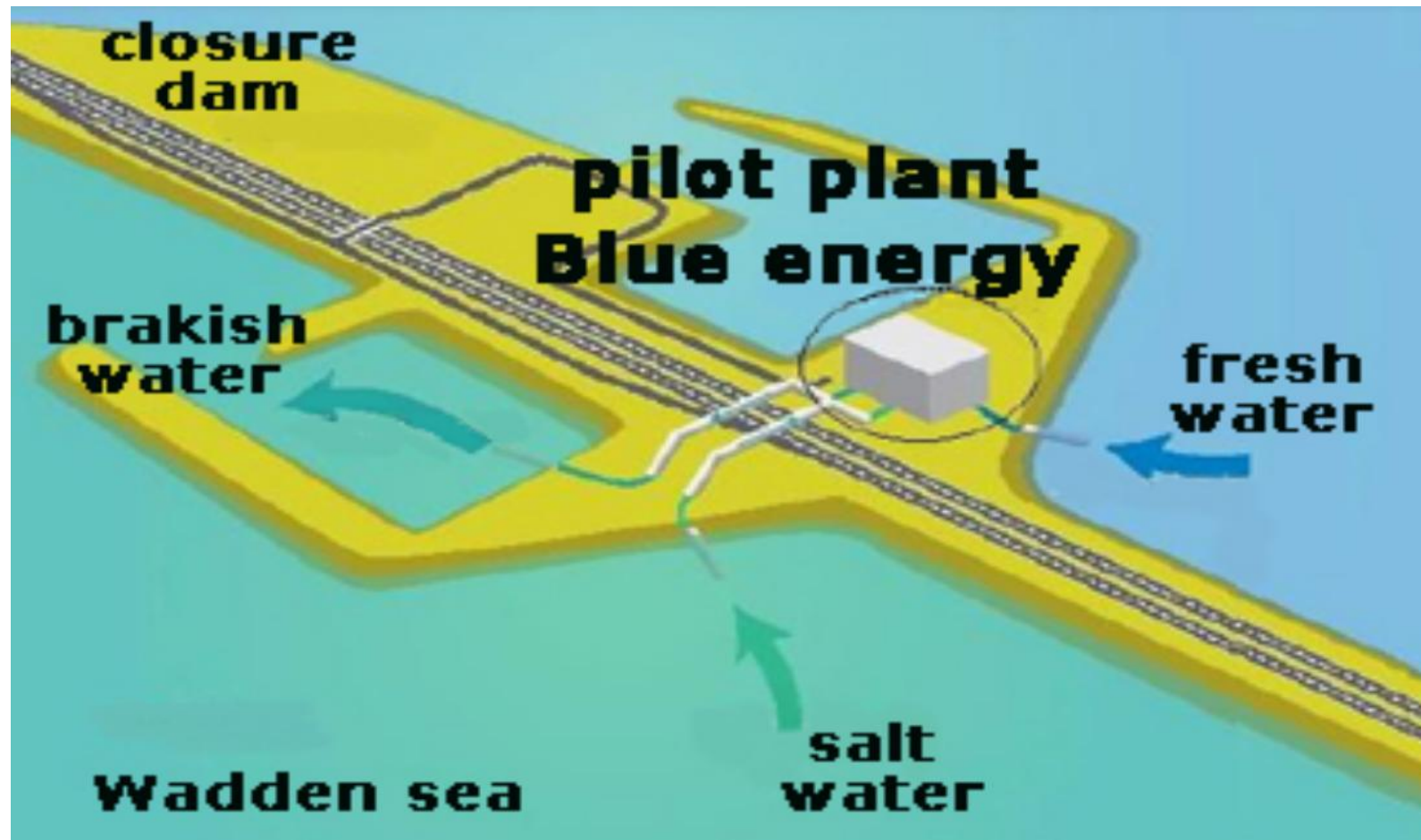
ELECTRIC POWER GENERATION BY OSMOSIS



The generation of “osmotic power” uses the osmotic pressure difference between fresh river water (hypotonic) and salted sea water (hypertonic)

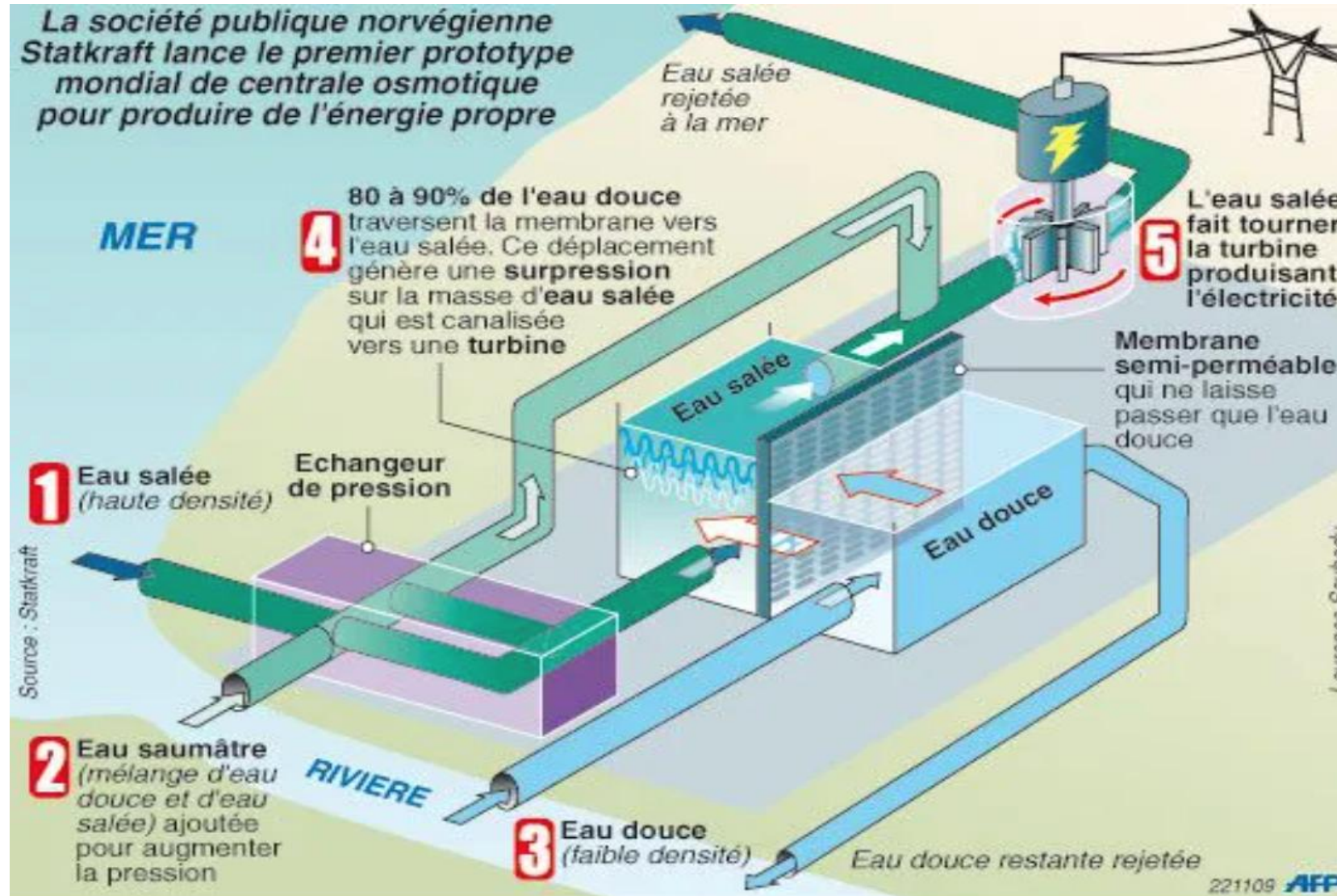


Prototypes in Netherlands, Norway, France

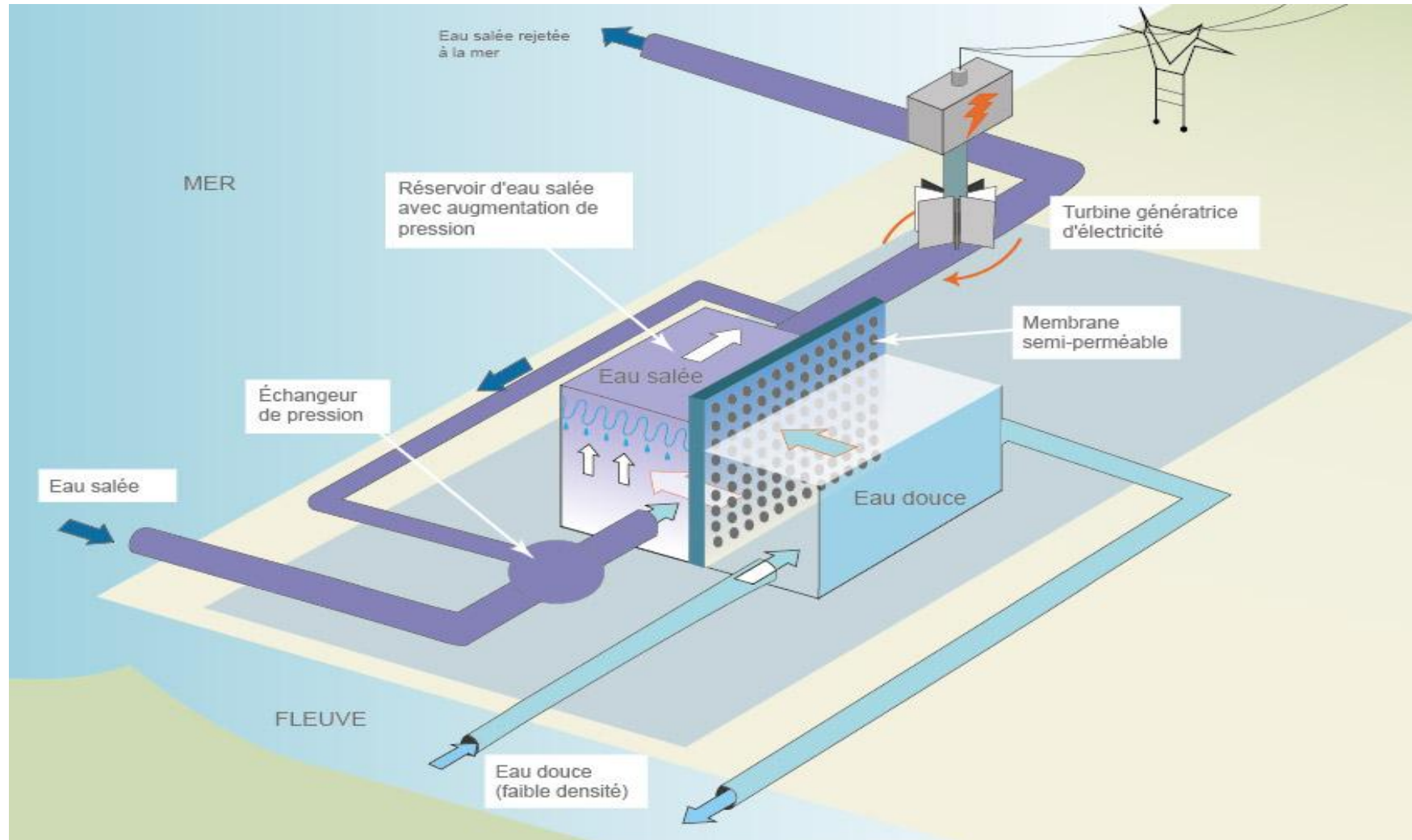


*Joint development of Redstack, FujiFilm and institute Wetsus
Afsluitdijk dam- Netherlands .*

Osmotic station



Osmotic station



Osmotic station



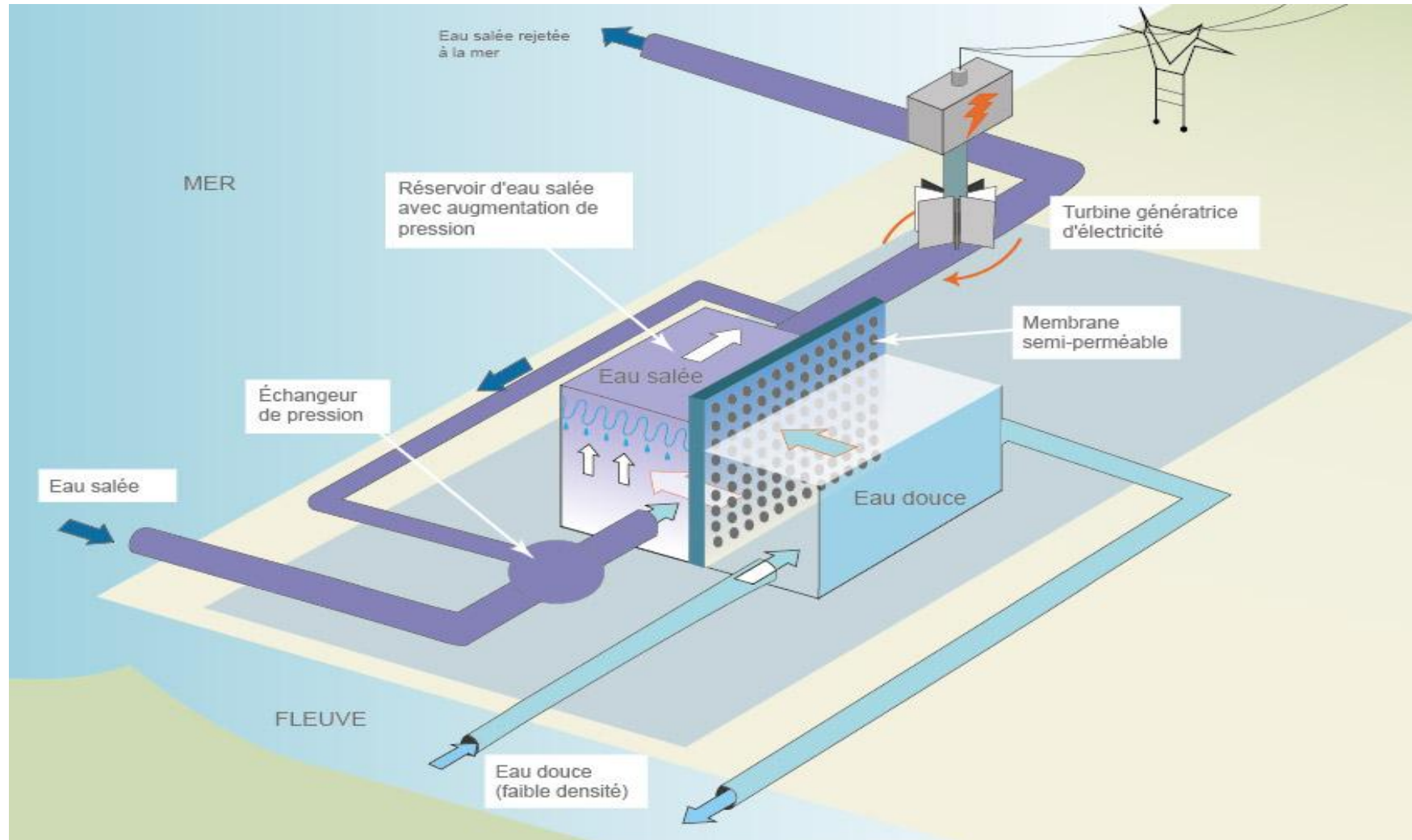
Osmotic station



Osmotic station



Osmotic station



Osmosis electricity production outlook

What about environment ?

The pilot plant on the Afsluitdijk produces 50 kWh of blue-energy , using fresh IJsselmeer water and salt water from the Wadden Sea. But at this current location the potential production of blue-energy could be sufficient for the energy requirements of 500,000 households.

Global prospect :

An exploration of suitable rivers in the world shows that there is a potential electricity production of 1,600 TWh annually.

Environment :

No CO2 emissions but necessary attention to sea life:

Each species of aquatic plant and animal is adapted to survive in either marine, brackish, or freshwater environments.

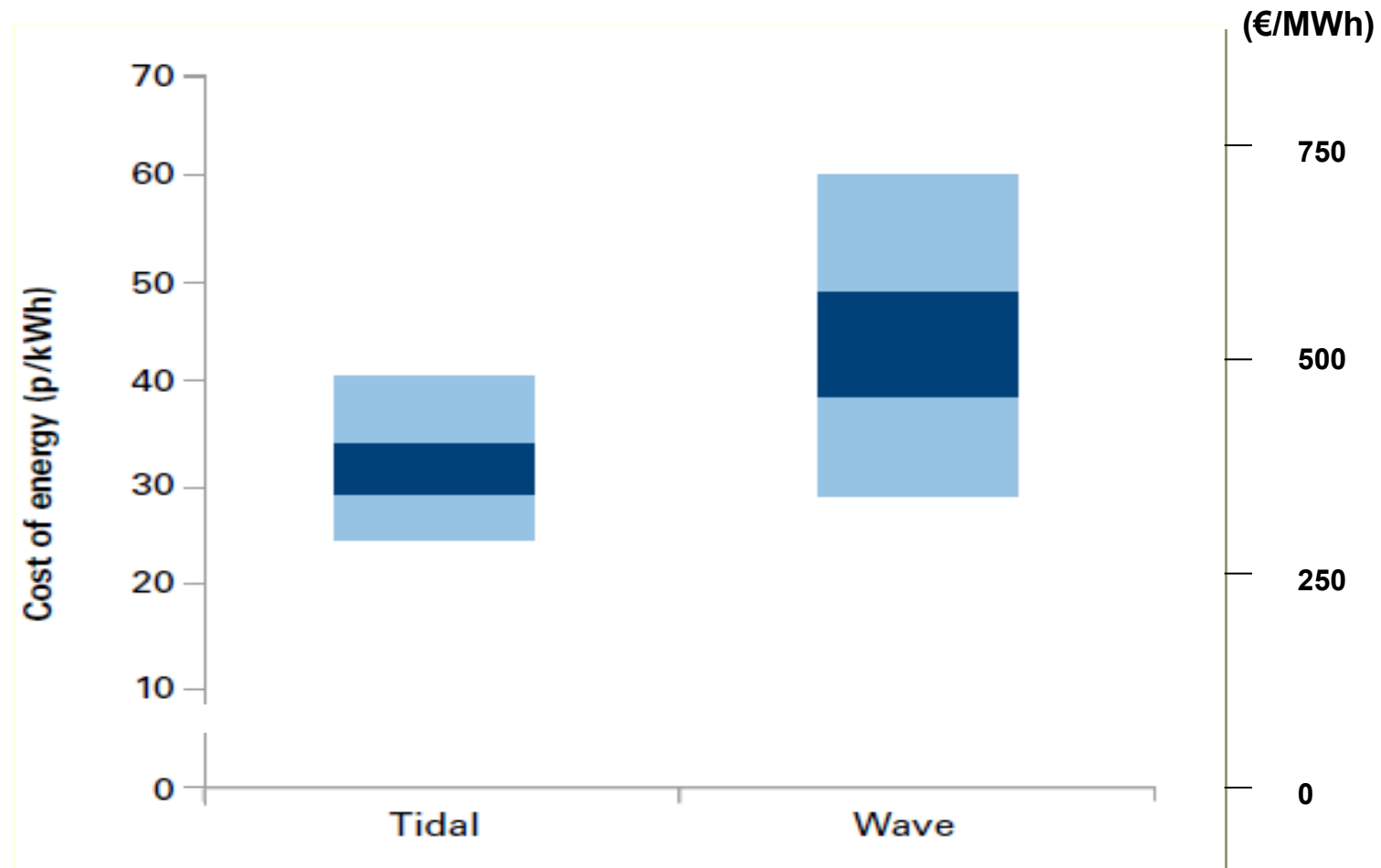


6-10

Costs, LCOE

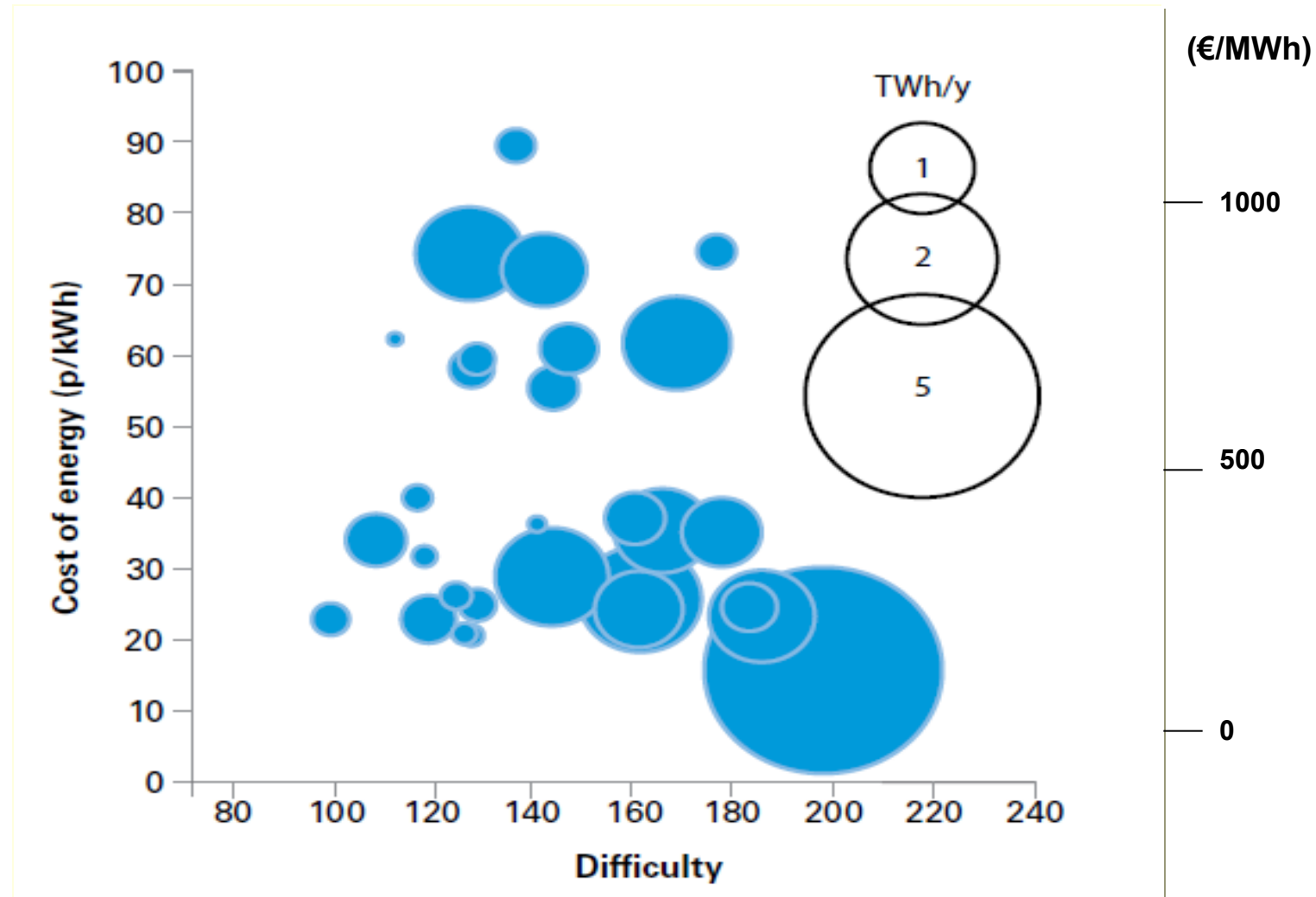


Cost range of Marine Energy (Tentative)



UK tidal stream sites

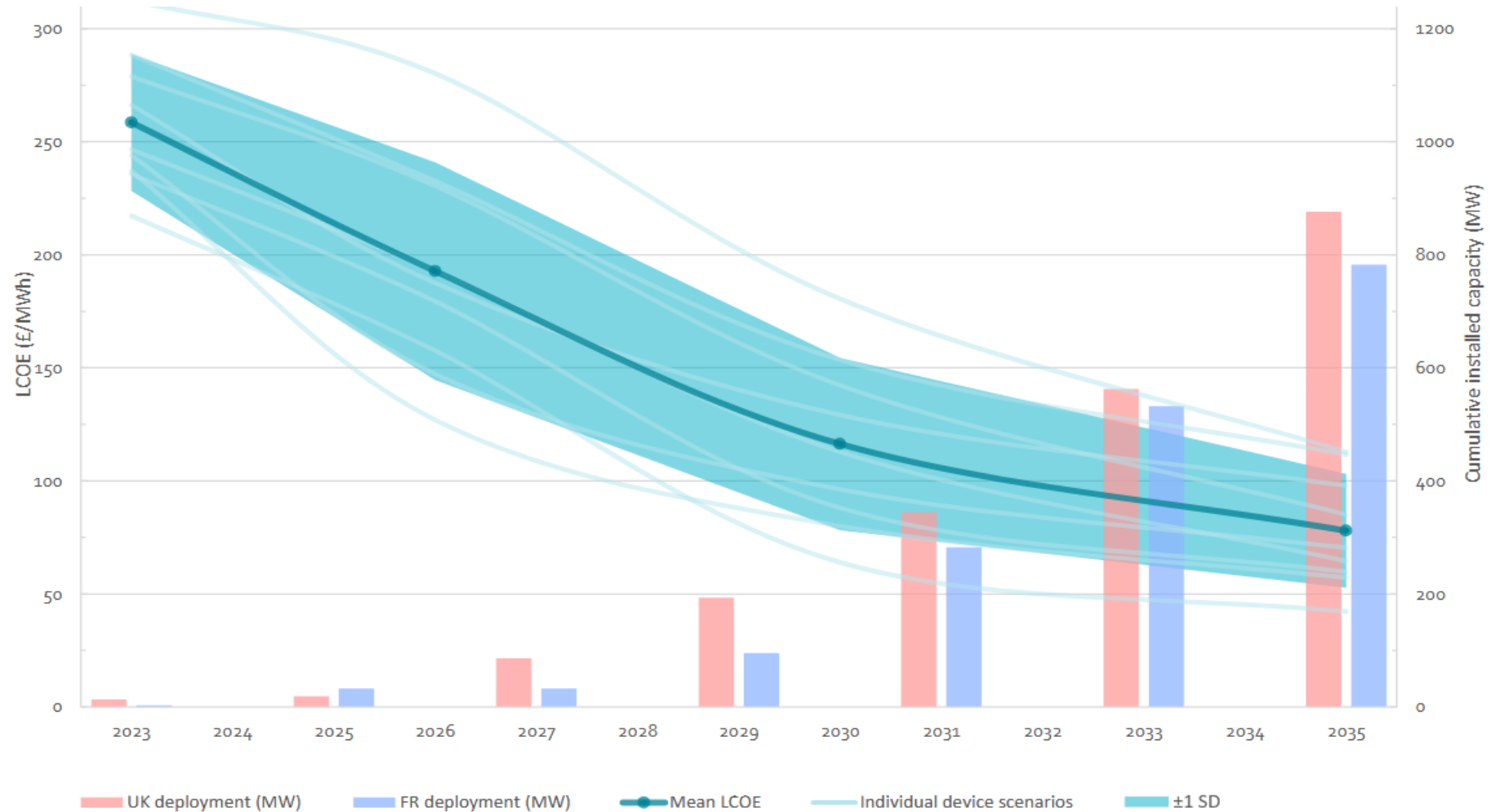
Uncertainties on costs



Source; Carbon Trust



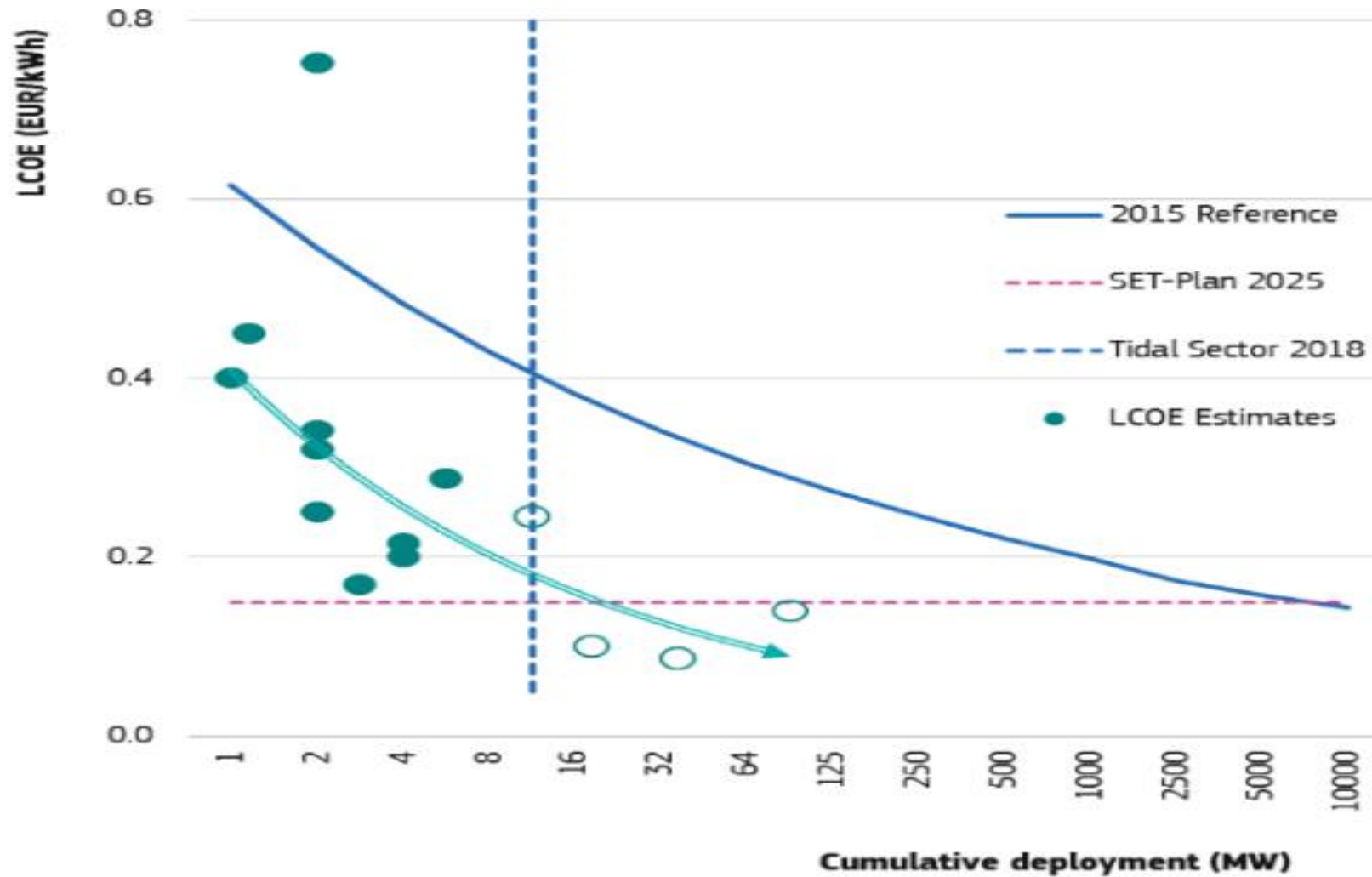
LCOE Estimates for Tidal Stream Energy in UK & France



UK and French TSE market projection and associated LCOE trajectories for the three devices and nine cost scenarios examined.



LCOE Estimates for Marine Technologies - Uncertainties on costs



Source; Trinomics – European Commission
Study on Energy Costs LCOE July 2020





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