Sahara wind

The role of Hydrogen from the trade winds in North Africa's broader renewable energy transition

The Sahara Wind Project

European Hydrogen Energy Conference

EHEC - 2013

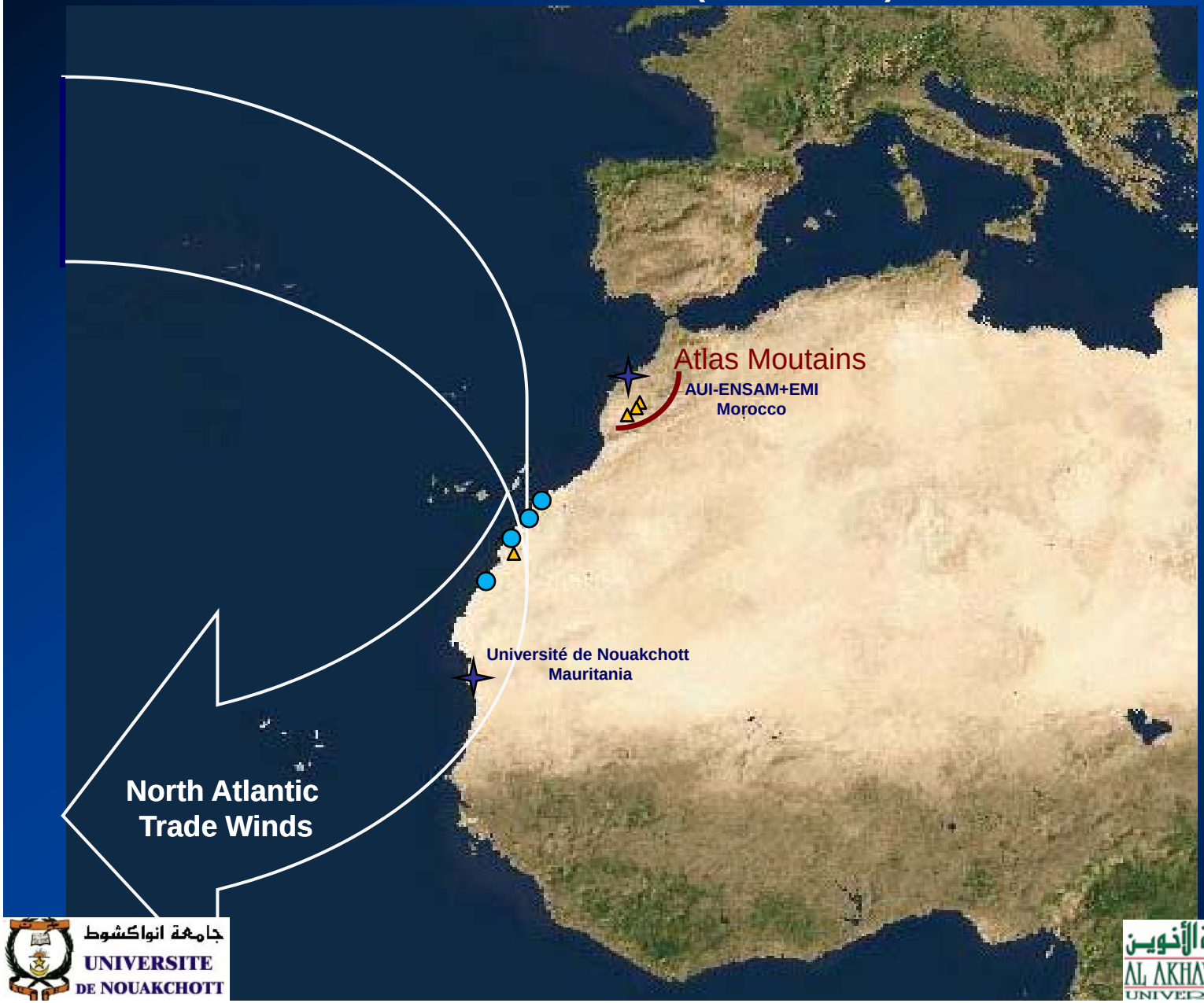
March 13th, 2014
Seville, Spain

Khalid Benhamou
Managing Director - Sahara Wind

NATO OTAN
Securing our Future
1949-2009
Garantir l'avenir de notre sécurité
This project is supported by: The NATO Science for Peace and Security Programme

Sahara wind

Sahara Wind - NATO SfP-982620 / (SfP-984382) frameworks



Trade Winds Existed for Millions of years: Geological Evidence Provided by World's Largest Sedimentary Phosphate deposits

▲ Phosphate deposits: 75% of World reserves*
(*U.S. Geological Survey 2013)

● Sea Water Desalination Plants

جامعة انواكشوط
UNIVERSITE DE NOUAKCHOTT

جامعة الأخوين
AL AKHAWAYN UNIVERSITY

Sahara wind

REGIONAL CAPACITY BUILDING
NATO 'SfP' Projects Coordinated under the Sahara Wind Project

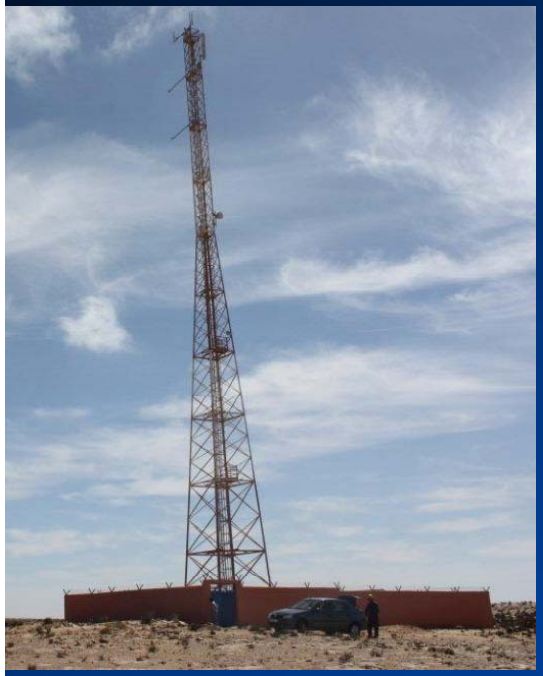
<u>Security Issue:</u> Energy Security - Climate Change - Social Unrest / Migrations
- Priority Research Areas of NATO Med Dialogue Partners: Morocco & Mauritania
- NATO New Strategic Concept: Emerging Security Challenge Division

Access to Wind Energy is a key research priority for Morocco & Mauritania:
- ✓Engage education and research in national energy choices
- ✓Reinforce scientific competence by securing intellectual property rights
- ✓Stimulate local innovation & research
- ✓Provide integrated solutions & mobilize largest energy consumers (R&D projects)
- ✓Develop synergies within academic-industry networks (electricity, water, minerals…)
- ✓Complementary working teams on a regional level (Morocco & Mauritania)

Technology – University/R&D Platform – Industry

NATO OTAN
Securing our Future 1949 - 2009 Garantir l'avenir de notre sécurité
This project is supported by: The NATO Science for Peace and Security Programme

Sahara wind



Partnerships with Telecom Operators of Morocco and Mauritania

NATO OTAN

Securing our Future · · · 1949 - 2009 · · · Garantir l'avenir de notre sécurité

This project is supported by: The NATO Science for Peace and Security Programme

Mast Measurements at 70, 50 and 40 meters height

Al Akhawayn University & University of Nouakchott
Green Campus Concepts

- Industrial engineering program on small wind turbines (ENSAM)
- Wind turbines connected to Universities electric grid (AUI & UNkt):
- 20 kW-Alkaline Electrolyser integrated into the system
- 48 cylinder pressurized hydrogen storage
- Excess Wind-electricity stored as hydrogen and converted back into electricity through stationary fuel cell for grid back-up/Telecom power supply…

NATO SfP- 984382 Project Plan: Rabat ONEP-IEA Institut International de l’Eau et de l’Assainissement - Station de traitement complexe Bouregreg - Direction Générale (ONEE) ‘Green Corporate Centre’ Training/Demonstrator (EMI-Rabat)

Sahara wind

Production of Drinking Water in Arid Regions using Renewable Energies
Integrated Electrolysis End-User Market Application

Wind speed: Measured through NATO SfP-982620/(984382)
Wind-Electrolysis for Electricity, Chlorine (Hypochlorite) and Hydrogen

ONEE- Water Branch Morocco (767 millions m3 water/yr)
1- Rabat: ONEE corporate headquarters at water treatment plant
'Green Corporate Campus' concept (Demo-Training)

- Small Wind Turbines
- Hypochlorite (Membrane) Electrolyser
- Hydrogen storage
- Fuel Cell (Grid backup+ Eco-mobility Demo)

2- Desert site: ONEE desalination plant

- Larger Wind Turbine(s)
- Hypochlorite (Membrane) Electrolyser
- Integrated processing industries

Perspectives: Water treatment in Sahel region
Collaboration with SNDE & University of Nouakchott
Energy-intensive mineral processing industries (Phosphates, Fertilizers industries)

NATO OTAN
Securing our Future 1949 - 2009 Garantir l'avenir de notre sécurité
This project is supported by: The NATO Science for Peace and Security Programme

Sahara wind

NATO Science for Peace SfP-982620
Integrated Electrolysis End-User Market Application

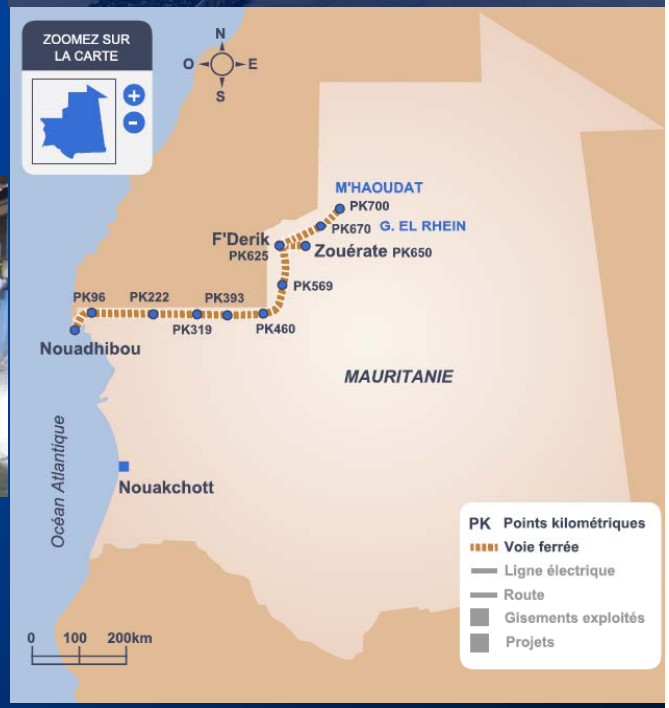
Wind speed: Measured through NATO SfP-982620/(984382)
Wind-Electrolysis for Electricity, Hydrogen,Oxygen

Case Study: SNIM foundry (SAFA company)
Nouadhibou Installed Capacity: Diesels (15+18)+4.5 MW Wind
SAFA power needs: Electric Arc Furnaces: 3 MW + Oxygen plant + Induction Ovens : 2 MW
Objectives for Pilot Project:

- Wind Turbine(s)
- Alkaline Electrolyser
- Hydrogen, Oxygen storage
- FC, ICE-generator (backup power)

SAFA (2 000 t/yr) supplies local needs for construction iron, cast-iron spares, fishing industry, etc.

Potential perspectives: 16~40 Mtons iron-ore annual exports can be processed into higher value iron/steel products (CO2 free) in a high Wind-penetration system.



NATO OTAN
Securing our Future · · · 1949 - 2009 · · · Garantir l'avenir de notre sécurité
This project is supported by: The NATO Science for Peace and Security Programme

Sahara wind

Mauritania's Iron-ore industry

- Largest industrial conglomerate: Société Nationale Industrielle et Minière SNIM (State-owned 78%)
- Reserves in billion(s) ton range, 28% of Mauritania's GDP, 50 % of country's total exports in value
- Africa's second largest iron-ore exporter (13 Mt/yr. in 2013 expanding to 40 Mt/yr. by 2025)
- Mauritania's iron-ore markets split between Europe and China
- EU-markets constrained due to environmental dusts emissions (pre-processing required)
- Direct Iron Reduction option for EU iron-ore exports :
    - Alkaline Wind-Electrolysis
    - Hydrogen: main feedstock for Direct Iron Reduction process (DRI)
    - Hot Direct Reduced Iron (HDRI) fed into Electric Arc Furnace: Steel production (energy savings).
    - Oxygen burned in Electric Arc Furnace (~45% of World Steel production)
    - Operating costs of direct reduction plants low compared to integrated steel plants
    - Suitable for many developing countries where supplies of coking coal are limited
    - Smaller in capacities, direct-reduced iron plants enable firming of wind-electricity.

        ⇒Creation of a high-grade, sustainable, carbon-free steel industry

Testing, training and capacity building at University of Nouakchott, wind measurements (pilot project sites)

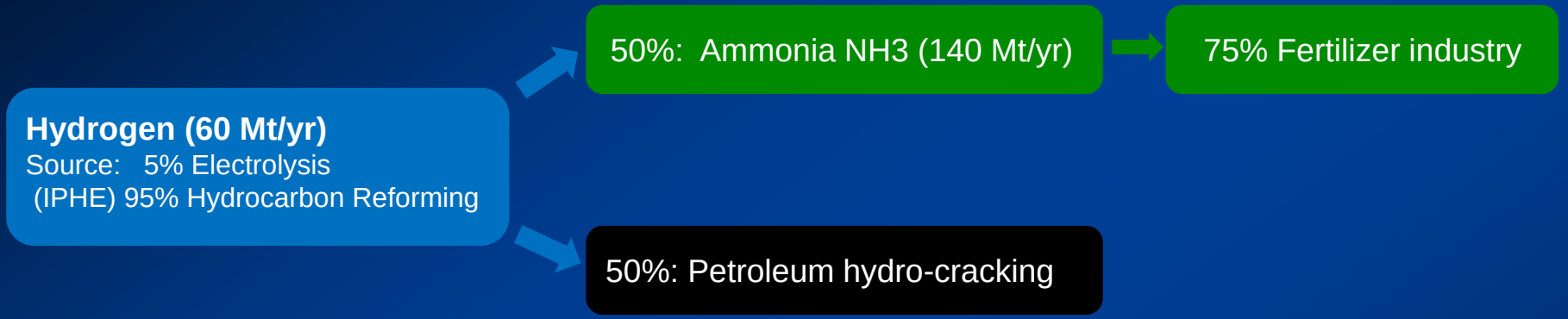
Sahara wind

Morocco's Phosphates industry

- Largest industrial conglomerate: OCP Group (State-owned 94%)
- 75% of World Reserves, ~8% of Morocco's GDP, 33 % of country's total exports in value
- World's largest exporter of:
  - Phosphate rock: 27 Mt in 2013 (35% Market share, 50 Mt/yr capacity by 2015)
  - Phosphoric Acid : 3.3 Mt (47% Market share, 10 Mt/yr capacity by 2020),
- World's second largest exporter of Fertilizer: 4.5 Mt (20% Market share)
- High price fluctuations in current Phosphoric Acid wet-process using Sulfuric Acid (Sulfur and Ammonia imports needed for the production of upgraded Fertilizers).
- Endogenous Phosphoric Acid production alternatives (electricity intensive):
  1- Thermal (or furnace) process: Phosphoric Acid production (electro-thermal process)
  2- Hydrochloric Acid Wet-process: Phosphoric Acid production (electrolysis process)
    ⇒Chlor-Alkali electrolysis
    ⇒Hydrochloric Acid from Chlorine (water added) for Phosphoric Acid production
    ⇒Co-generated Hydrogen: feedstock for Ammonia (NH_3; Nitrogen picked from air)
      - Creation of integrated fertilizer industry (Phosphates+Wind+Water)
      - Sustainable processing (enhanced resource transformation efficiency)

Saharawind

End-uses of Hydrogen in the Economy



- Ammonia represents 50% of the world's Hydrogen end-uses, ¾ used for production of upgraded fertilizers
- Fertilizer industry is largely captive, integrated and endogenous (70% is located near phosphates deposits)
- Price for Phosphate rock, Sulfur and Ammonia fluctuate significantly: good margins opportunities for producers with their own supply of rock.
- Fertilizer industries are essential to world food security:
  - When World Population reaches 9.2 billion people by 2050: arable land per capita will fall by 20%
  - Biofuels will exacerbate this trend
  - Sustainable Hydrogen for producing Ammonia is a critical issue.
- With Food Security at stake -since 90% of the Phosphates are used as fertilizers- the transformation of the world's most significant Phosphates reserves becomes a key element of global sustainability.
- Cost-competitive incorporation of wind energy in support of endogenous energy intensive value-added mineral transformation processes is likely to significantly improve resource efficiencies.

Sahara wind

Global Sustainability Considerations
Perspectives from China's Fertilizer Industries

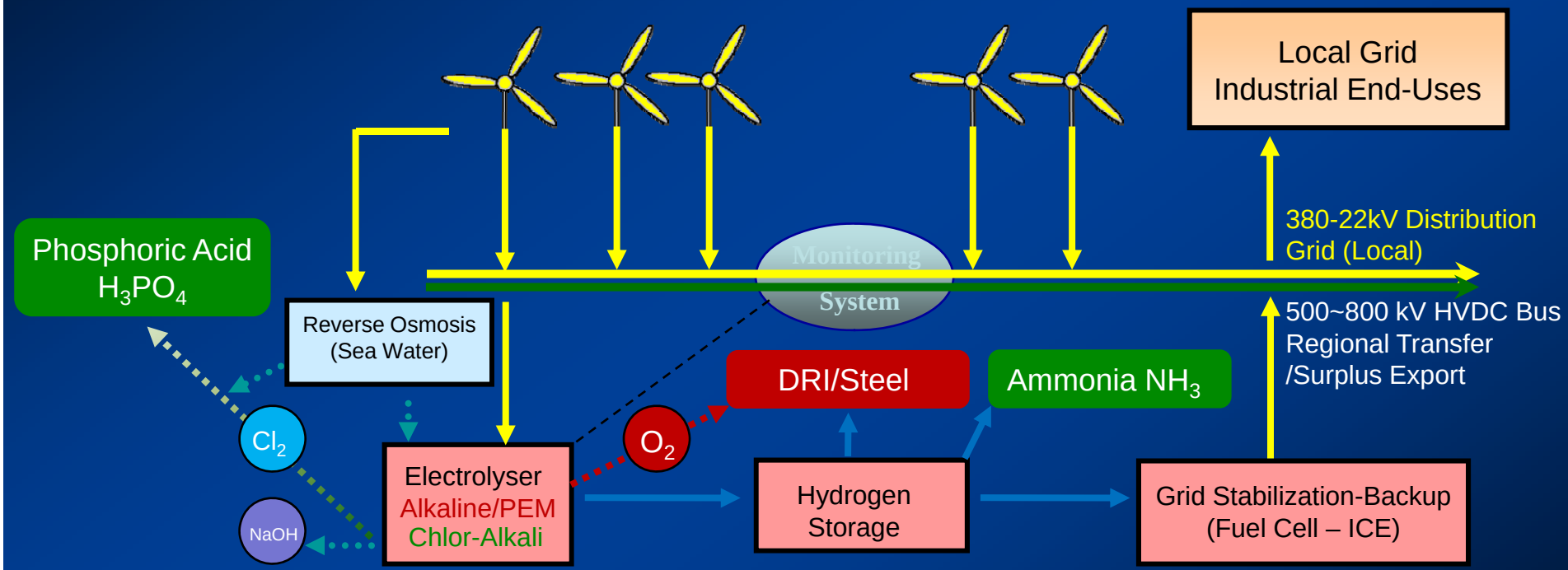
Morocco's Phosphate industry (27 Mt/yr, Phosphoric Acid 3.3 Mt/yr)

China's Phosphate industry (80 Mt/yr, Phosphoric Acid 15.0 Mt/yr)

- Integrated fertilizer industry, largely endogenous, domestic use (80% export tariffs imposed)
- Hydroelectric power supplied inexpensive power to phosphoric acid plants for many decades:
  - Largest thermal phosphorus production capacity.
  - China produces and consumes one-third of the world's Ammonia.
  - Majority of new Ammonia capacity is expected to come on-line in China (for internal consumption)
- China's global lead in Wind energy generation (15-20 GW of new capacity per year; 50% of world market), comes with non-negligible grid stability and balancing issues.
- Wind energy predisposed favorably in the transformation of Phosphates, and fertilizer industries.
- Considering the extraordinary scale of the region's phosphate (and iron-ore) resources, synergetic processes are critical to support the local firming of the trade winds in the operational balancing of the Sahara Wind project's GW size HVDC line.

Sahara wind

Integrating Sahara Trade Wind Resource into Local Grids in Support of North-Africa's Major Industries



Processing of Phosphates (Morocco)
World Market shares: Phosphate Rock 33%, Phosphoric Acid 47%, Fertilizers 20%

Processing of Iron-Ore (Mauritania)
16 MTons (Actual) 40 MTons by 2025, large Reserves

Sahara Wind Project: Dispatchable Renewable Power

Water, Phosphates/Fertilizer,
Iron-Ore Processing …

Gas Pipeline - Network

Underground Cavern

Automotive Industries

Natural
Gas

Combined Cycle
Power Plant

High Pressure
Electrolyser

Transmission
Grid

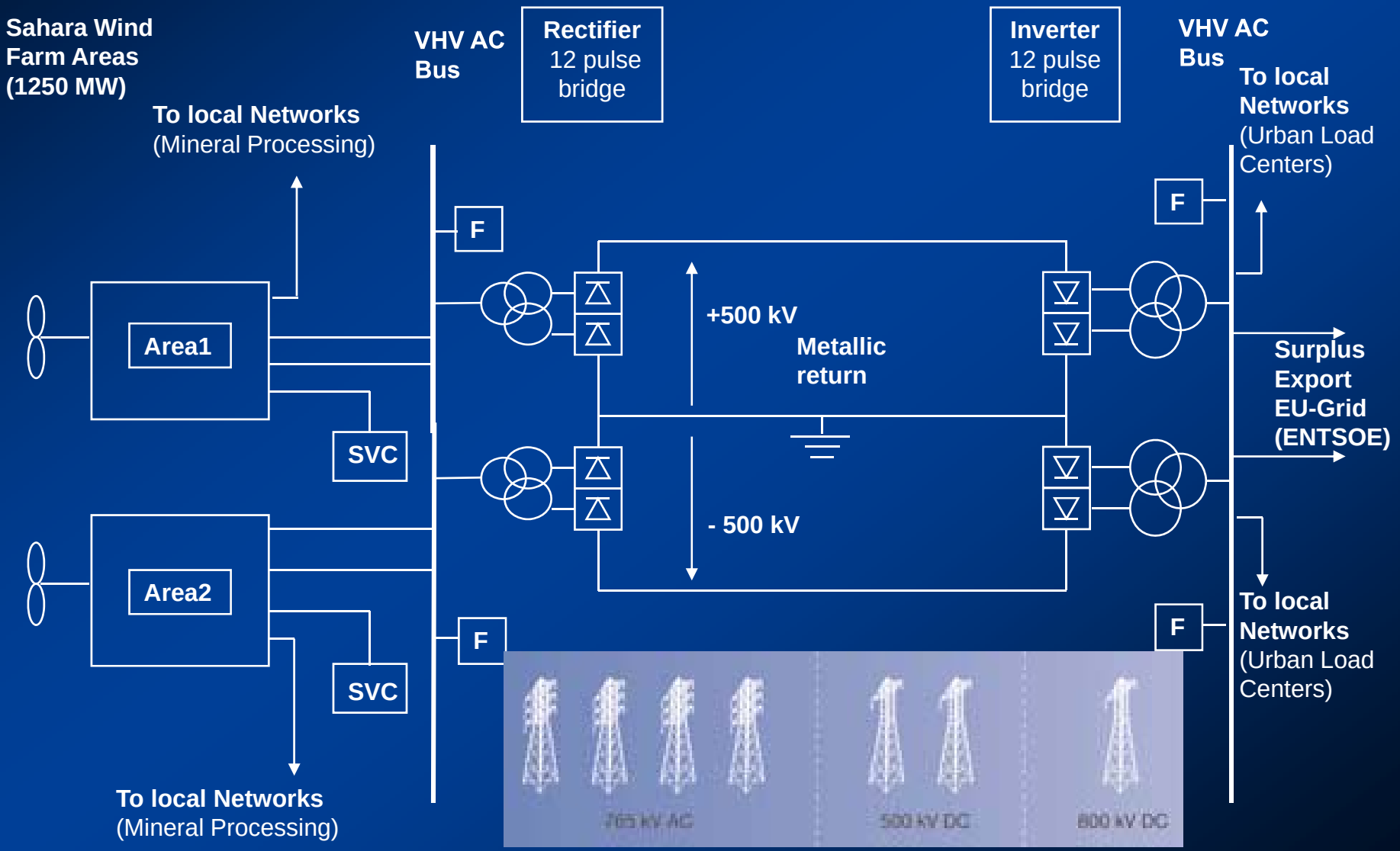
Hydrogen

Electric Power

Sahara Wind 1500 km HVDC Line

Sahara wind

Sahara Wind - HVDC Transmission Architecture 5 GW - bipole 1
(Point to Point classical HVDC configuration)



Sahara wind

HYDROGENICS

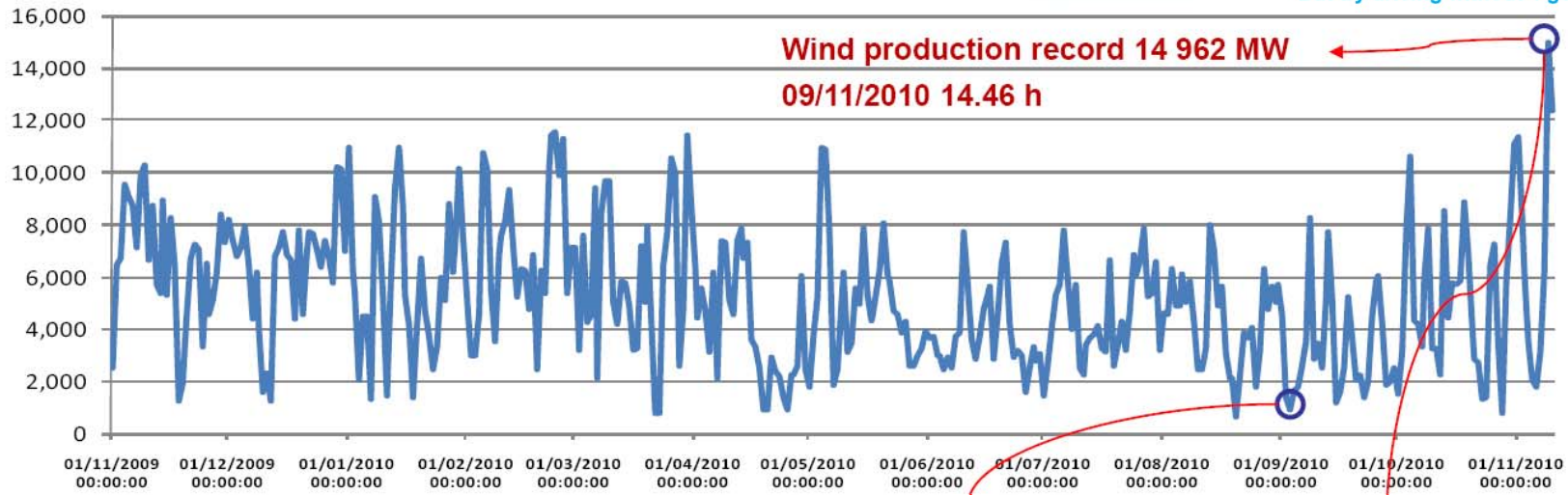
Not the biggest, most expensive
or most important part of your car

Dynamics & Capacity

But try driving without 4 good ones!

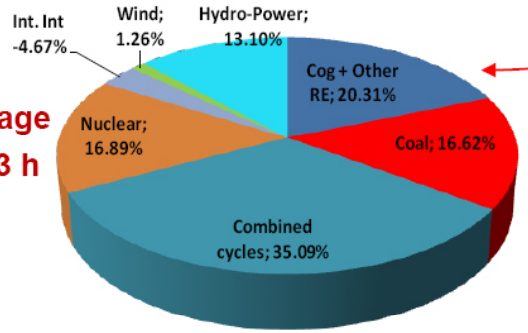
RED ELÉCTRICA DE ESPAÑA

Wind production variability

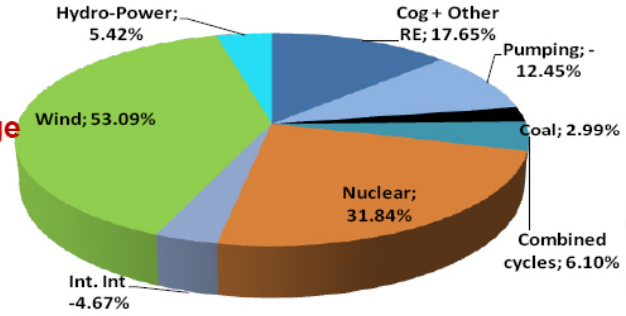


Wind production record 14 962 MW
09/11/2010 14.46 h

Minimum coverage
03/09/2010 12.33 h



Maximum coverage
09/11/2010 3.35 h



RED Eléctrica de España latest figures: with 28% of total power generation, wind energy is Spain's main source of electricity (January-February 2014, 21% in 2013)

Saharawind

Moroccan Integrated Wind Energy Program: 2GW
(Export Possibilities Not Included)

- End 2014 : 1 GW (487 MW in operation + 450 MW under construction)
- By 2020 : + 1 GW (850 MW + 150 MW Integrated Wind Energy Program)

2 GW Total

Accessing the Sahara trade winds:

- Morocco's total generating capacity (6677 MW) / Peak load (5280 MW)
  => Possible wind power integration can hardly exceed 2 GW
- Wind potential far away (1300 km+) from load centers => HVDC transfer
- Wind manufacturing industry requires big capacities

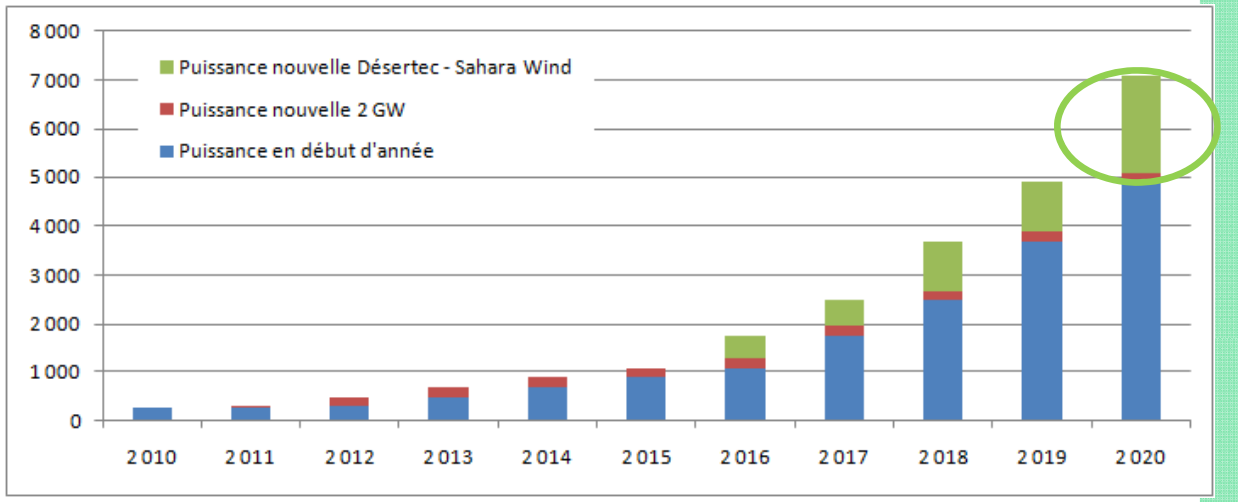
⇒Large-scale regional integrated project development approach is needed:

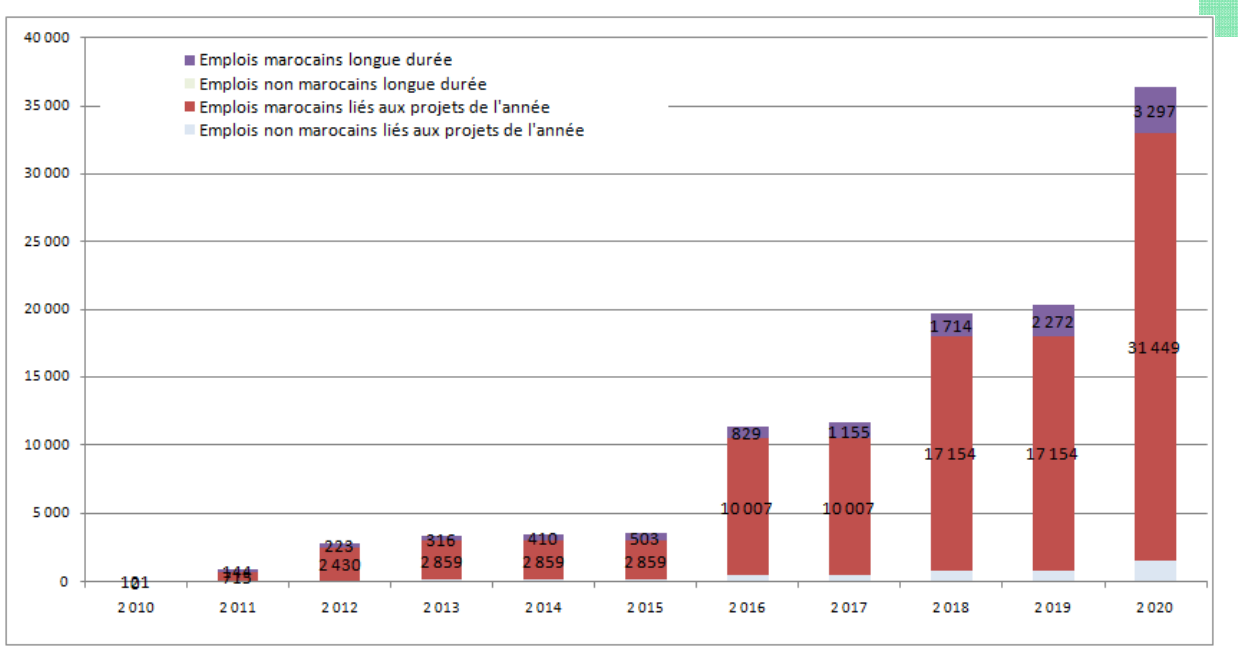
The Sahara Wind Project (5GW+ HVDC line)

Scénario alternatif : Sahara Wind

Hypothèses :

- 5 GW supplémentaires installés en 2020
- Intégration industrielle 95%
- 500 MW installés/an en 2016 et2017
- 1 000 MW installés/an en 2018 et 2019
- 2 000 MW installés en 2020





Emplois non marocains liés aux projets de l'année	1 551
Emplois marocains liés aux projets de l'année	31 449
Emplois non marocains longue durée	30
Emplois marocains longue durée	3 297
	36 327

Sahara wind

The Sahara Wind Project (5GW+ HVDC line)

RD&D is a Prerequisite for Optimal Deployment of the Sahara Wind Project
Sahara Wind Phase 1: 50~500 MW on existing grid / Extensions through HVDC lines

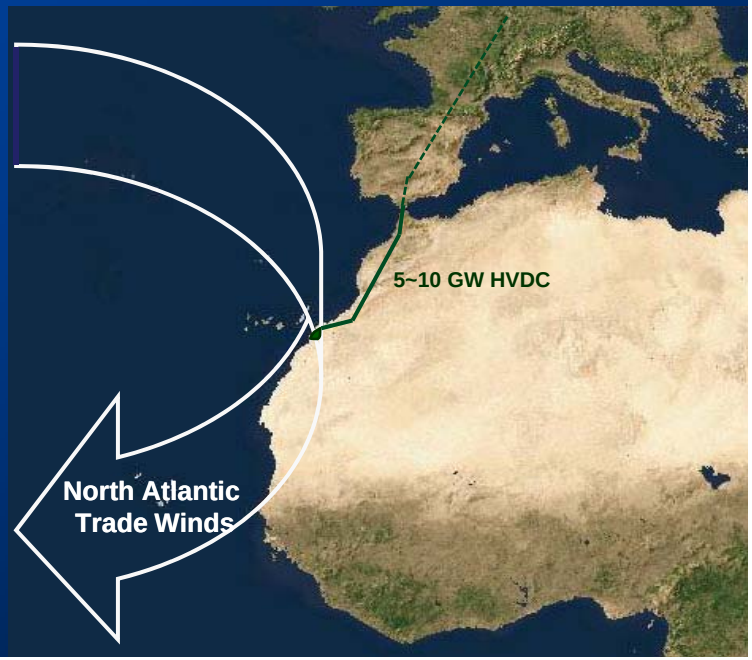
HVDC Technology:
• Limited losses –long distance (3% over 1500 Km ±500kV for 5000 MW)
• 140 GW of HVDC in 145 Projects worldwide. China has 25 multi-GW projects (40% of its new 300 GW grid capacity will be HVDC), USA 10 multi-GW projects(2011), India, Brazil..

North African electricity markets are in full growth/expansion (8%/yr.)

Wind catchment area: Quality-Quantity-Proximity
-Quality: Average wind speed: 9 m/s+ (trade winds)
45% Capacity Factor

-Quantity: Size of Area: Saharan coast 2000 km+
Morocco, Mauritania & Senegal
Potential Wind Energy 500 GW(?) ~ 1000 TWh(?)

-Proximity: 1500 km from European Union
500 million citizens, +3000 TWh/yr power market



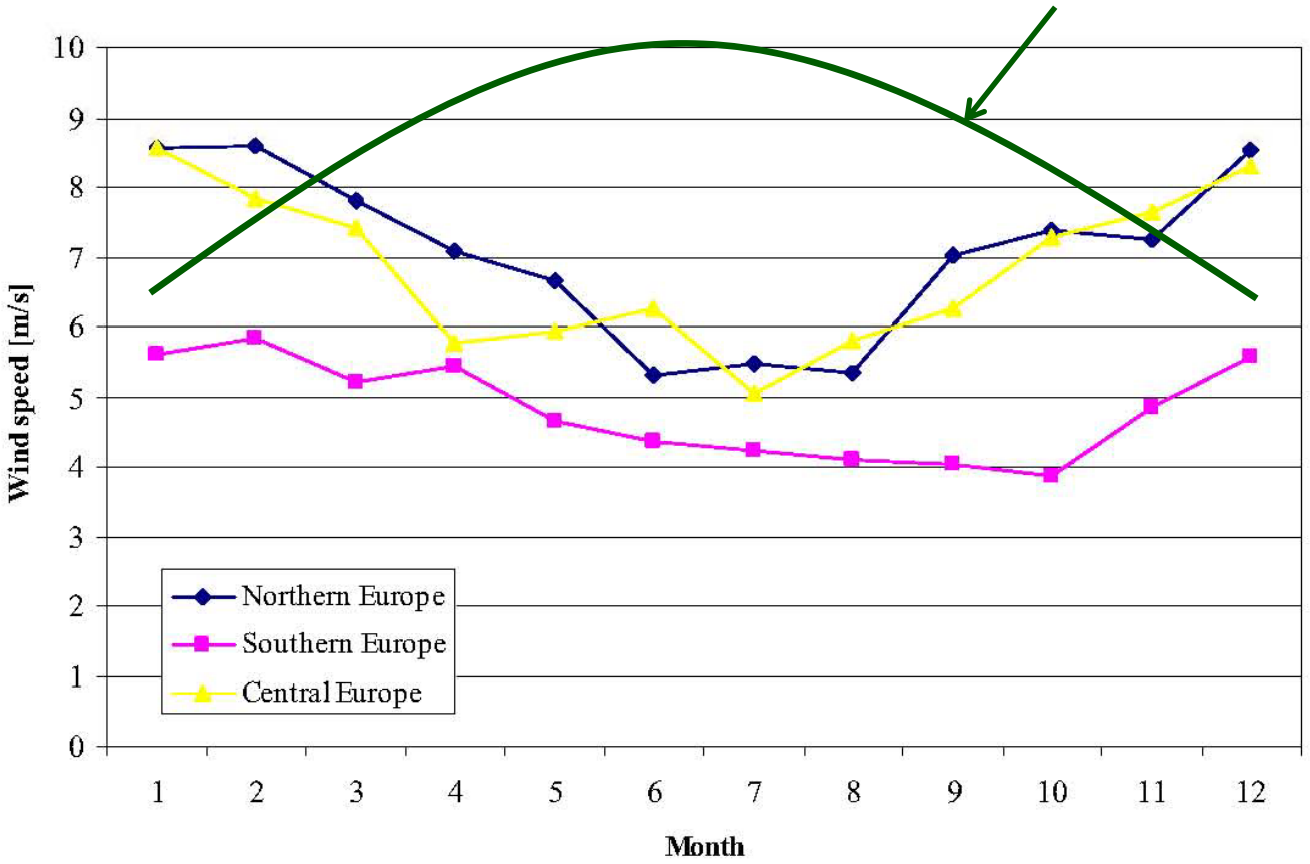


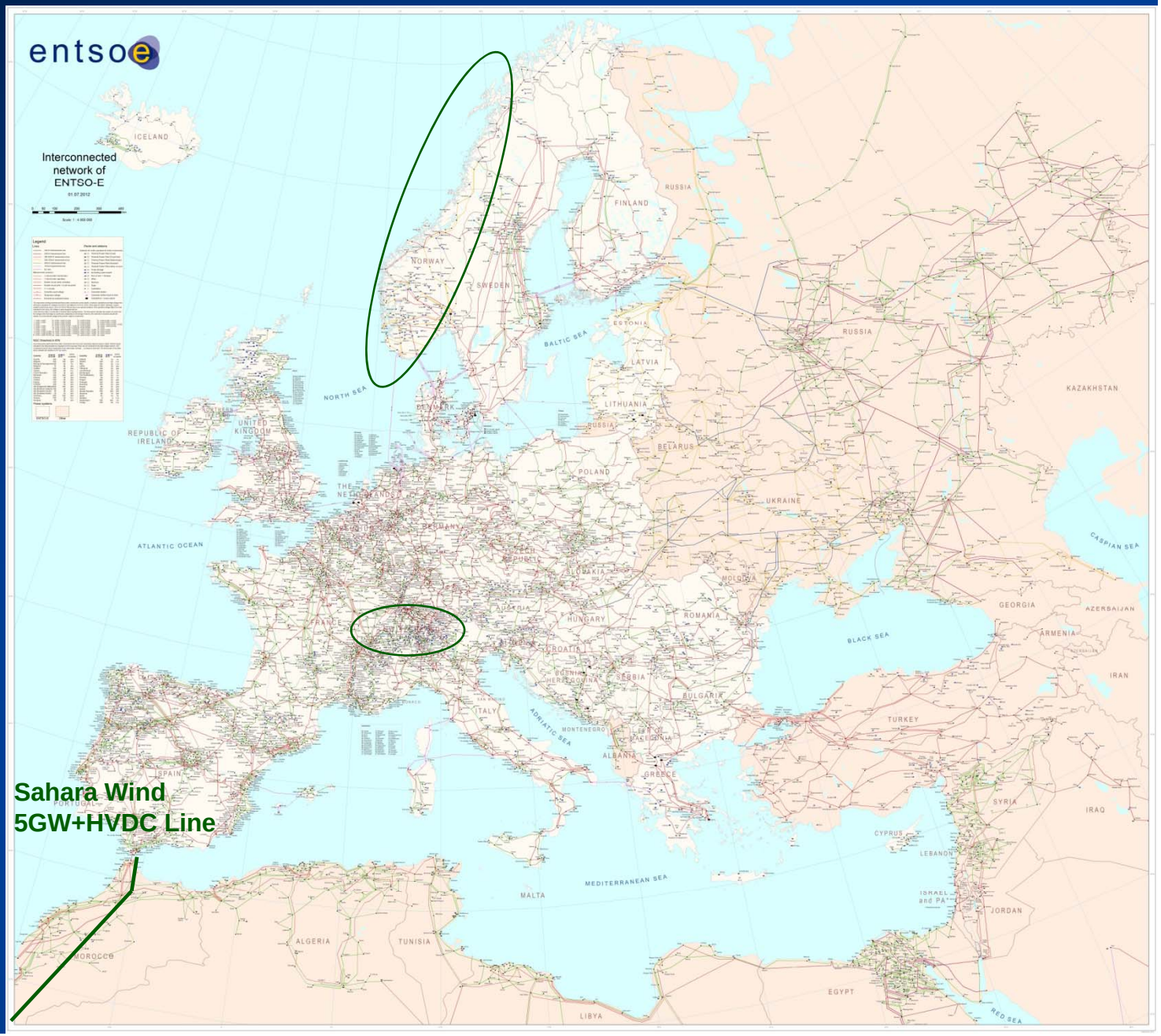
Figure 2.4 Seasonal trends in Reanalysis wind speed

Source: EU funded TradeWind Project, (WP2.4; Characteristic Wind Speed Time Series - Document Number: 11914/BT/01C)

Sahara wind

ENTSOE
Grid Map
of
North Africa &
Europe

Integration of
the 5GW
Sahara Wind
Project HVDC
line
into European
Synchronized
Grid



Sahara Wind-Hydrogen Development Project of the International Partnership for the Hydrogen Economy

Renewable Hydrogen Production

Sahara Wind-Hydrogen Development Project

Morocco and Mauritania

The trade winds that blow along the Atlantic The trade winds that blow along the Atlantic coast from Morocco to Senegal represent one of the largest, most productive wind potentials available on Earth. The same region currently suffers from a limited, decentralized grid infrastructure in need of stabilization. The Sahara Trade Winds to Hydrogen Project aims to utilize these Saharan winds to produce hydrogen in order to enhance the access and integration of wind electricity in Morocco and Mauritania. The project uses a phased approach, beginning with demonstration projects in academic settings to build capacity and knowledge and later moving on to larger projects in industrial settings.

Coordinated by Morocco's Sahara Wind Inc., this project began in the second half of 2007 and is expected to last three years. The project team is composed of 10 partners from Morocco, 8 from Mauritania, and 4 co-directors from the United States, Germany, Turkey, and France.

Objectives

The erratic nature of the trade winds resource means that wind energy cannot provide a sustainable source to the region's weak infrastructure, prohibiting any conventional approach of a continuous feed into smaller local electricity markets. The size of Morocco's grid is also relatively small (~5,000 MW) and cannot handle large amounts of wind-generated electricity before encountering grid stability problems, such as generation intermittency and power margins. These problems escalate further south in Mauritania where the grid capacity is less than 120 MW.

Therefore, the most beneficial approach is believed to be the use of wind electrolysis as a means of grid stabilization within integrated applications utilizing electrolysis by-products such as hydrogen for power storage restitution/backup, or as a fuel or feedstock for specific uses in remote locations.

The Sahara Wind-Hydrogen Project has led to a NATO "Science for Peace" SfP-982620 Sahara-Hydrogen contract aiming to accomplish the following goals:

- Use electrolyzers as a stabilizer in weak electricity grids
- Co-develop wind-electrolyzer systems for local conditions
- Map regional wind resource potential
- Build "Green Campus Concepts" with hydrogen storage
- Develop integrated wind electrolysis applications within the region's industries and load centers

Trade wind resource assessment using telecom tower infrastructures

Project Overview

What

Sahara Wind-Hydrogen Project

Who

Sahara Wind Inc.

When

Started: 2007
Duration: 3 years

Participants

Lead Country
Morocco

Partner Country
Mauritania, US, Germany, Turkey and France

Renewable Technology

Wind

Renewable H_2 Production

This project will demonstrate hydrogen production from wind electricity along with hydrogen storage used as a feedstock for specific industries and hydrogen shipping via pipeline.

Website

www.saharawind.com

Contacts

Project Director:
Mr. Khalid Benhamou
Sahara Wind Inc.
kb@saharawind.com

Sahara Wind-Hydrogen Development Project

Approach

The initial phase of the project is being carried out through applied research programs in academic settings in order to develop local expertise in the technologies. This is being done through the deployment of wind electrolysis systems within "Green Campus Concepts" programs at several universities in Morocco and Mauritania for demonstration and training purposes. The systems use a series of small 5 kW wind turbines that simultaneously provide power to the grid and to a 30 kW pressurized alkaline electrolyzer. The electrolyzer produces hydrogen, which is then stored in cylinders at a pressure of 12 bar and used in a 1.2 kW fuel cell to produce electricity and stabilize the grid at times of low wind speed.

After being initiated at the universities, the technology will gradually be extended to the region's industries. Current plans are to install demonstration systems followed by larger pilot projects at Morocco's water and electric utility's corporate headquarters and main water treatment plant, as well as at the Tarfaya desalination plant. These systems will consist of small wind turbines powering hypochlorite (membrane) electrolyzers. The hydrogen is stored and used in a fuel cell and internal combustion engine generator for back-power, as well as being used as fuel for electro-mobility applications. A similar project using alkaline electrolyzers and wind turbines will be put in place at Mauritania's iron ore company in the city of Nouadhibou.

Accomplishments

Small wind turbine industrial engineering programs have been established at several universities, enabling development of the technological expertise that will be needed to support the planned and future demonstration projects.

The project has also enabled a wind monitoring infrastructure to be deployed in both Morocco and Mauritania with the help of the project's industrial partners. Both of the telecom operators in Morocco and Mauritania have made their telecommunication mast tower infrastructures available for this project, enabling a regional wind mapping network to be established. Atmospheric parameters such as pressure, temperature, humidity are being recorded in addition to wind direction and speed on International Measuring Network of Wind Energy Institutes (MEASNET) calibrated instruments at several tower heights. The wind mapping network is expected to facilitate future utilization of the area's trade wind resources by providing specific information about the quality of the resource over large geographical areas, thus enabling projects involving utilization of hydrogen to be deployed as part of a large-scale, integrated system using high voltage direct current (HVDC), local use of hydrogen, and hydrogen pipelines for export.

Future Plans

The wind and electrolyzer equipment for training and applied research purposes will be put into operation in early November 2010 at the Al Akhawayn University of Morocco and the University of Nouakchott in Mauritania. These systems will be gradually updated to increase their wind generation capacities, with a goal of providing system stabilization of up to 30% of base load.

Other small, wind-turbine test benches are being delivered to the Ecole Nationale Supérieure d'Arts et Métiers (ENSAM) School of Engineering in Meknes, Morocco, and will be installed in late 2010. The technical economic analysis for end-user pilot project applications has already been completed, including technical equipment configurations.

In the future, the project plans to partner with the region's industries representing the main local energy loads to build an integrated energy system complementary to Sahara Wind's High Voltage DC Transmission project. This system will use hydrogen storage and hydrogen shipping via pipeline. By enhancing the local ownership of wind resources on a regional basis and supporting industrial use of local mining resources using cleaner more sustainable processes, such a system could potentially serve as a secondary power source to both North Africa and Europe.

Ultimately, project participants would like to see this project enhance the integration of an end-user-driven, comprehensive, sustainable, applied research program. This is likely to lead to the adoption of a holistic, integrated approach to renewable energy technologies in North Africa.

Map showing the locations of two of the university projects (left). Schematic of Sahara Wind wind-hydrogen system (right).