NATO Science for Peace SfP-982620
Sahara Trade Winds to Hydrogen
Background & Perspectives

Regional Hydrogen Roadmap
Project Development Framework
for the Sahara Wind Project

Presentation at 12th Joint SC/ILC Meeting
International Partnership for the Hydrogen Economy
December 1st, 2009 – Washington DC, USA

By Khalid Benhamou
Managing Director - Sahara Wind Inc.
NATO Science for Peace SfP-982620
Partner country Project Director (PPD)

European Energy Security & Environement: Profile of Electricity Supply Sources (2003)

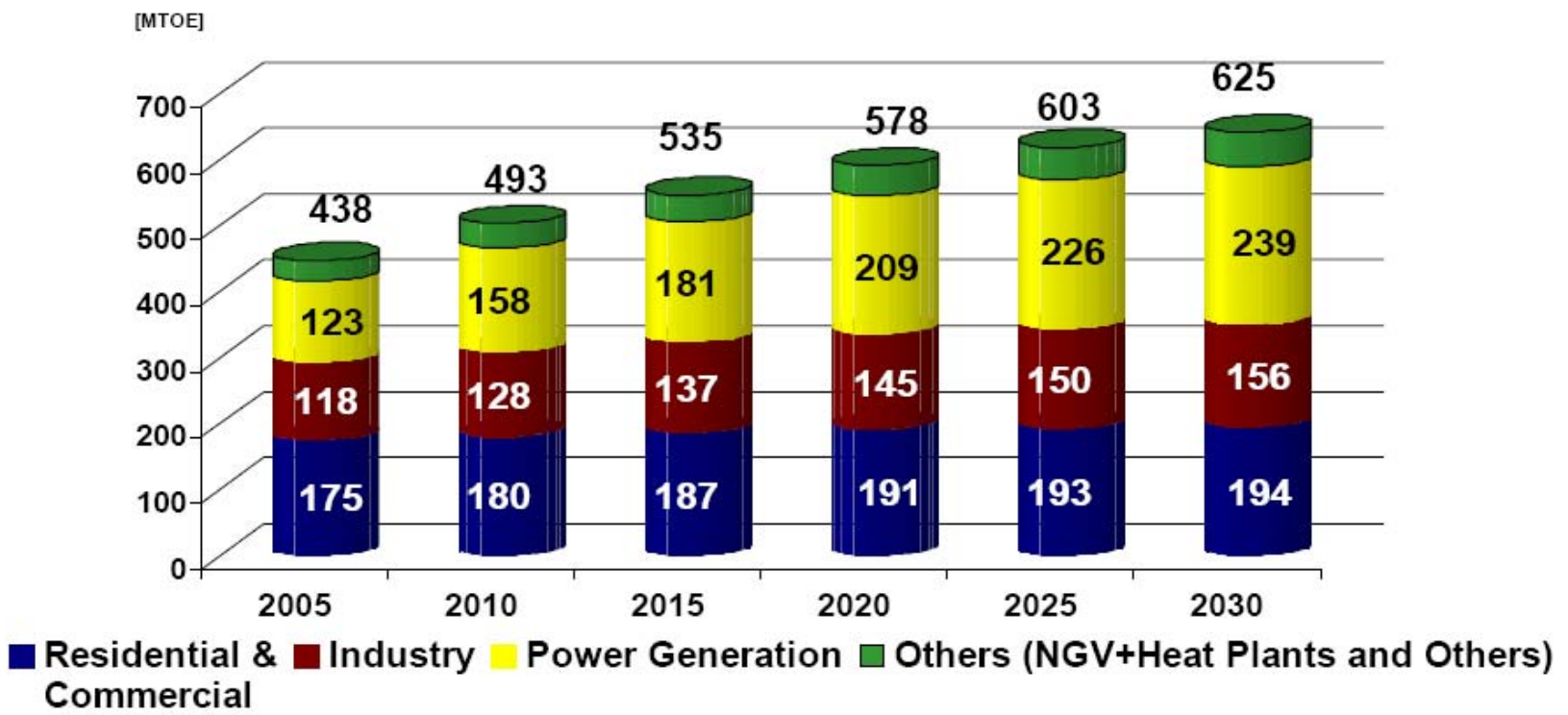
EU DG Transport and Energy: Previsions of installed electric generating capacities in Europe

Power generation capacity by type of plant in EU-25, 1995-2030.

	GWe					%Share	
	1995	**2000**	**2010**	**2020**	**2030**	**2000**	**2030**
Nuclear	134.7	140.3	129.8	108.0	107.8	21.4	9.5
Large Hydro (pumping excl.)	91.0	93.9	95.8	96.3	97.0	14.3	8.6
Small Hydro	2.0	2.1	8.1	12.2	14.5	0.3	1.3
Wind	2.5	12.8	73.5	104.7	135.0	2.0	11.9
Other renewables	0.0	0.2	0.5	0.7	14.3	0.0	1.3
Thermal plants	381.4	406.1	484.8	639.0	762.9	62.0	67.4
of which cogeneration plants	80.7	93.2	117.6	150.9	179.5	14.2	15.9
Open cycle - Fossil fuel	339.4	335.2	278.9	210.0	196.8	51.1	17.4
Clean Coal and Lignite	0.0	0.0	0.0	0.8	5.5	0.0	0.5
Supercritical Polyvalent	0.0	0.0	0.8	55.3	126.3	0.0	11.2
Gas Turbines Combined Cycle	20.0	47.3	173.3	313.8	367.4	7.2	32.5
Small Gas Turbines	21.2	22.7	30.6	57.8	65.5	3.5	5.8
Fuel Cells	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Geothermal	0.7	1.0	1.2	1.3	1.4	0.2	0.1
Total	**612**	**655**	**793**	**961**	**1132**	**100**	**100**
current EU	539	579	689	813	951	88	84
acceding countries	73	77	104	148	181	12	16

Source: PRIMES, ACE.

EU27 Natural Gas demand outlook



At 60% of the total demand increase, most of the growth will come from power generation.

Source: EUROGAS

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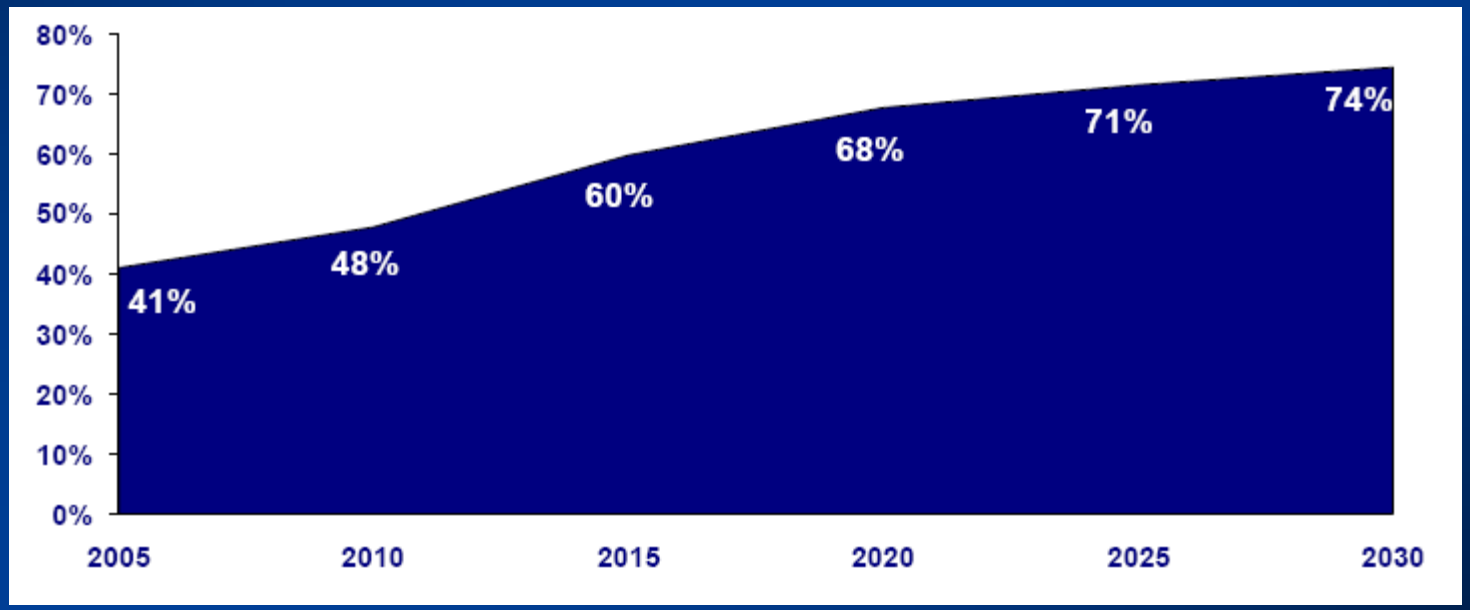
NATURAL GAS DEMAND AND SUPPLY
Long Term Outlook to 2030

EU27 import dependency from outside Europe



Source: EUROGAS

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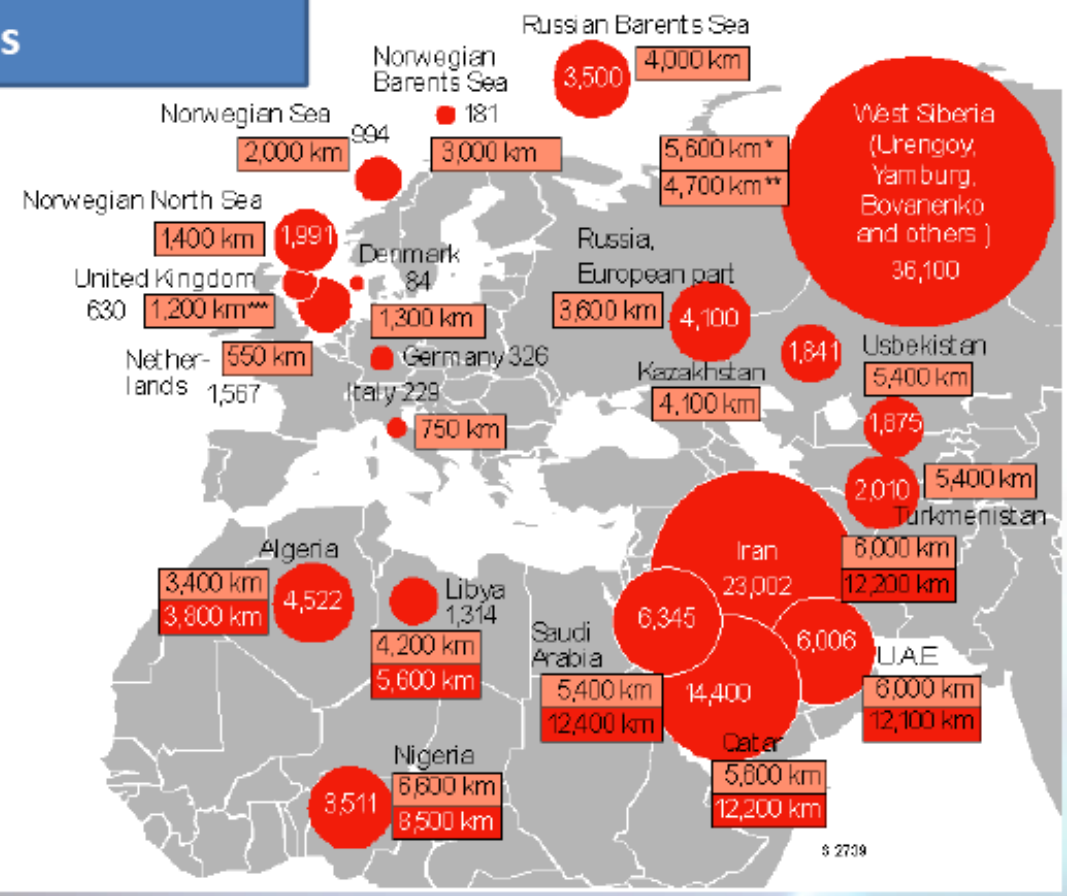
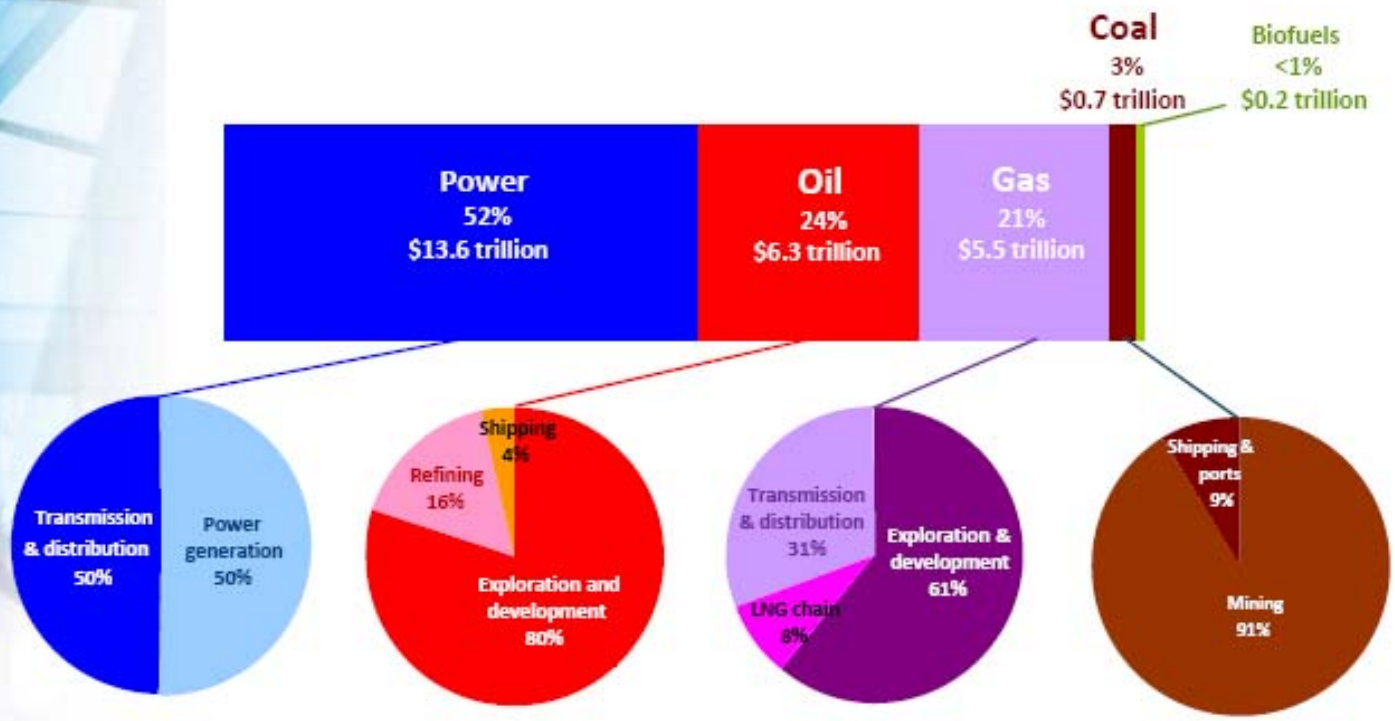
euro gas

Natural Gas reserves and supply distances

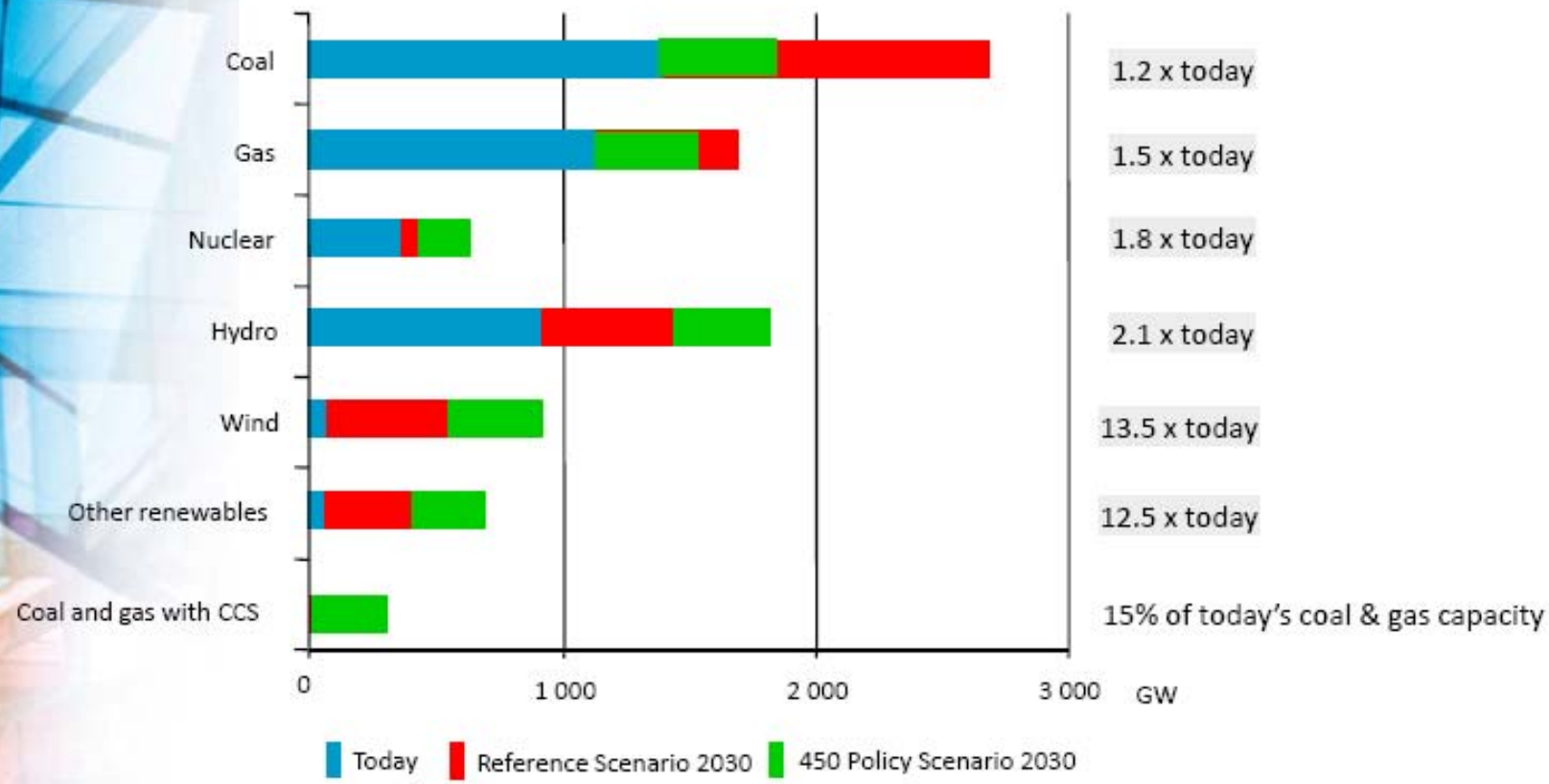


Cumulative energy supply investment in Business as Usual, 2007-2030



Investment of $26 trillion, or over $1 trillion/year, is needed, but the credit squeeze could delay spending, potentially setting up a supply-crunch once the economy recovers

Total power generation capacity today and in 2030 by scenario



In the 450 Policy Scenario, the power sector undergoes a dramatic change – with CCS, renewables and nuclear each playing a crucial role

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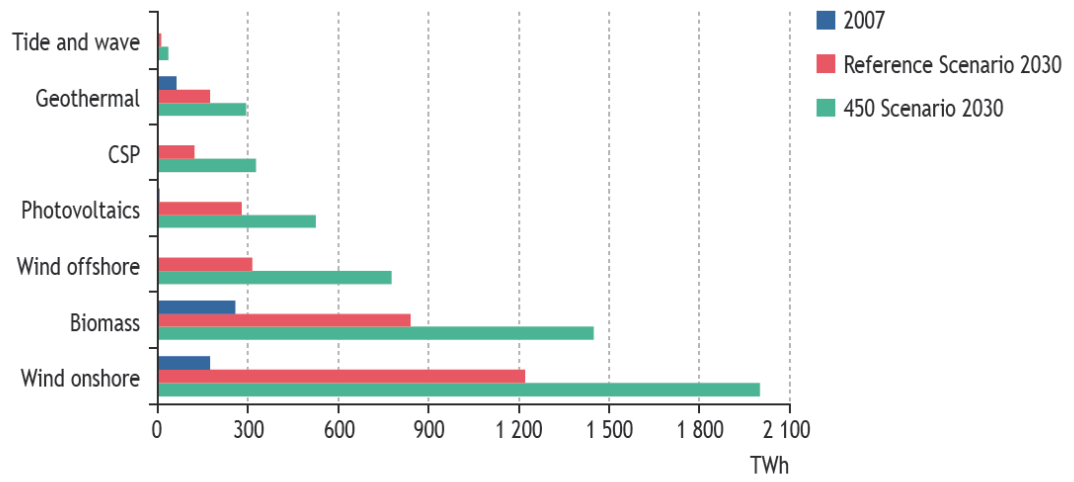
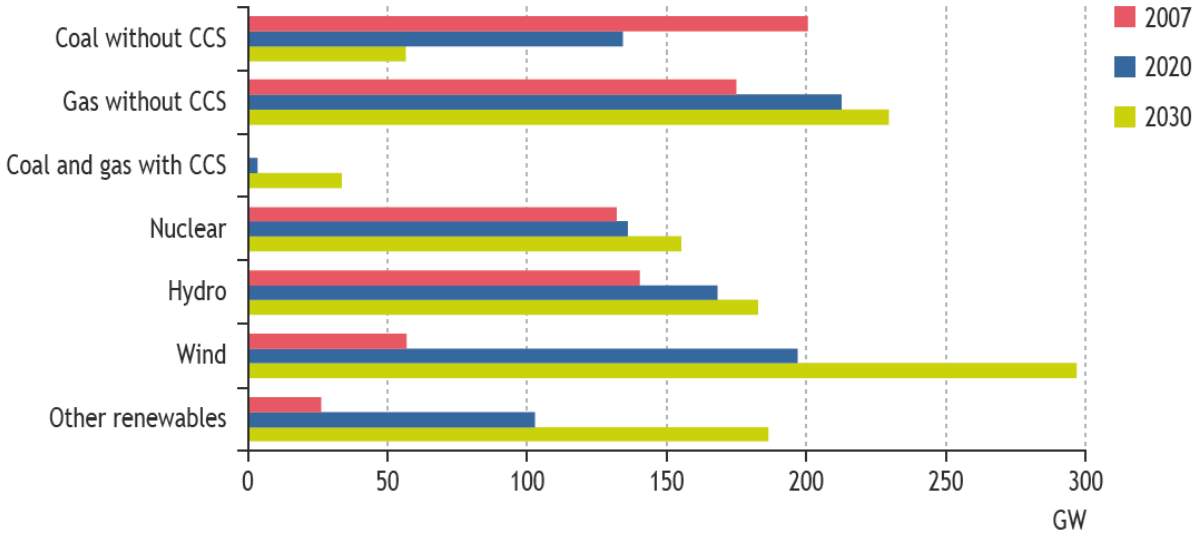
Renewable Hydrogen Production Prospects
&
IEA World Energy Outlook 2009
450 Scenario

Figure 5.11 • World electricity generation from non-hydro renewables by type in the 450 Scenario



Note: CSP refers to concentrating solar power.

Figure 9.18 • EU power-generation capacity in the 450 Scenario



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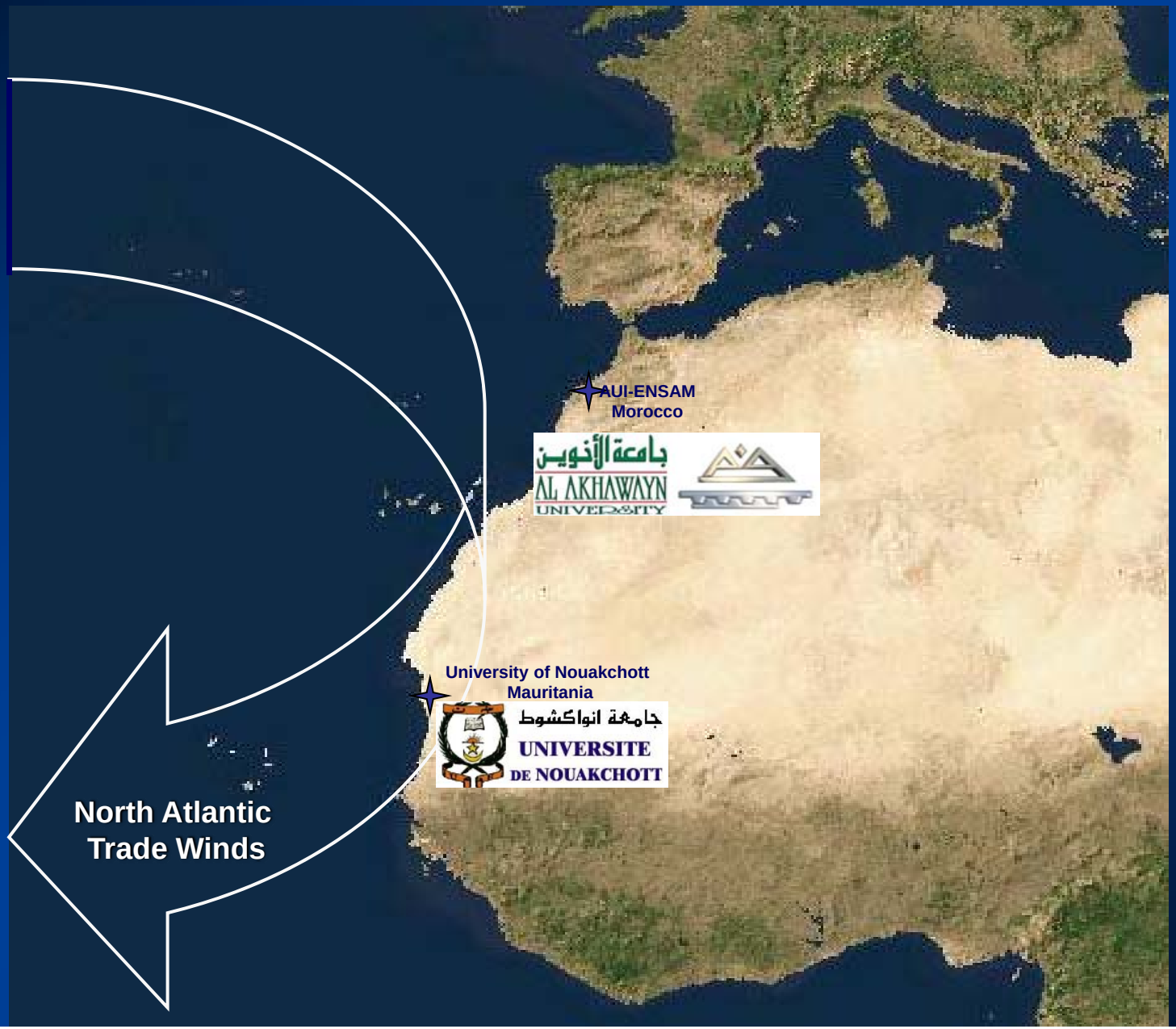
NATO 'Science for Peace' SfP-982620



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Sahara Wind Energy Development Project

Energy Access

•The Trade Winds are largest, most productive wind energy potentials on earth.

•Wind Energy: fast growing, most competitive renewable energy.
Technical issues with intermittency and grid stability (power margins, dispatching, reactive compensation, voltage, frequency regulation, flickers, harmonics…)

Problems are more acute in weak grid conditions
(handling wind energy fluxes with no interconnection possibilities)

Saharan Countries Total installed electric generation capacities:

Mauritania 160 MW, Senegal 239 MW, Mali 280 MW, Niger 105 MW, Chad 30 MW !

Unless far ranging, more advanced (flexible) energy technologies are considered
Wind Energy cannot be integrated locally on any significant scale.

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Wind Energy, Capacity Building and Energy Access

A strategy has to be developed for integrating Wind/RE technologies.

Potential risks of not integrating a strategy: Grid quickly saturates to Wind Energy (20% Wind easily reached in smaller grids!)

Wind Resource Assessment & Hydrogen energy : Integrated R&D Themes

- Holistic approach
- Broad ranging, integrated process
- Bottom-up capacity building
- Capitalize on available human resources and research institutions
- Create research networks and prevent technology gaps from widening
- Generate synergies with local industries (technology co-development)
- Countries with large Renewable Energy potentials and limited energy infrastructures more accessible to Hydrogen technologies (smaller scales).
- Stimulates wider regional cooperation

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REGIONAL CAPACITY BUILDING
NATO 'Science for Peace' Project Coordinated by Sahara Wind Inc.
NATO SfP-982620

Integrating Wind Energy Locally is a Key Priority for Morocco & Mauritania

Essential for Industrializing North Africa

Sustainable Energy Systems = Sustainable Energy Economy

- ✓Sustainable Mine Processing Industries
- ✓Renewable Energy Supply Networks

Mobilize Largest Energy Consumers (RD&D program)

- •Build SYNERGIES
- •Stimulate Local Innovation & Research
- •Provide Integrated Solutions
- •Mechanisms Against Global Climate Change (CTF, CDM, ….)
- •Security Issue: Energy Diversification & Fixing Migrant Populations

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Wind Energy in Morocco

Morocco's Current Targets in 2012: 1120 MW

Limitation factors: Grid Capacity…
Total Installed Generating Capacity 5000 MW (peak load 3000 MW)
- Big Wind Potential but Far Away from Load Centers (1000 km)
- No Plans for Transferring Wind Industry (small domestic capacity)

⇒Need to develop integrated approach:

The Sahara Wind Project (5GW)

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NATO SfP-982620 PROJECT METHODOLOGY

Complementary Working Teams through a Science for Peace Project Platform on a regional level (Academic and Industrial network) in Morocco and Mauritania.

This Partnership can benefit from other Partner countries of NATO, as well as NATO member Countries (Europe and North America)

Success measured not only in terms of intellectual property production, number of patents, etc. but also in terms of relevant partnerships essential in all applied research activities.

Technology <=> University/R&D Platform <=> Industry

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NATO SfP-982620 PROJECT OBJECTIVES

Reinforce Research Capacities Around Common Strategy – (on Regional basis)

- Sustainability of Energy
- Energy Technology Integration (Industrial Synergies End-Uses)
- Leverage Human Resources
- Reinforce Role of Education and Research in National Energy Choices
- Expand Knowledge Base in Advanced Energy Technologies
- Develop Scientific Competence in Securing Intellectual Property Rights of Research Groups & individual members.

NATO Intellectual Property Rights Committee => End-User Driven Approach

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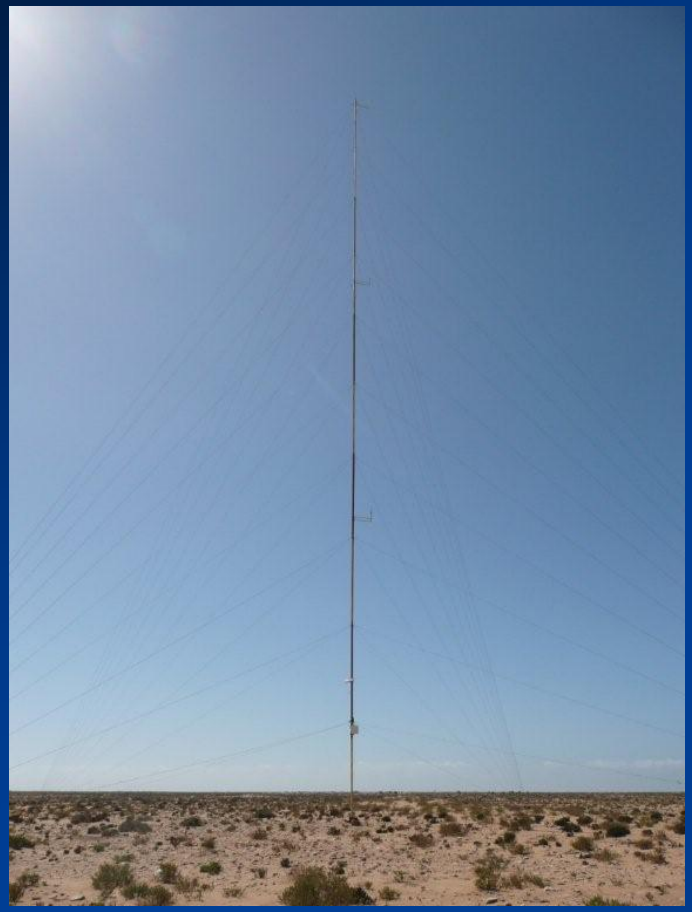
Wind Measurements



Area of Tarfaya (50 k€/Site)

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NATO SfP-982620 PROJECT OBJECTIVES
Synergies with Industry

Wind Resource Assessment:

Mauritania: Partnership Between University of Nouakchott and Mauritel

Morocco: Partnership Sahara Wind Inc. AUI and Maroc Telecom

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Wind Resource Assessment Methodology

Engage End-Users & Develop Effective Collaborative Protocols

Instrumentation (100% SfP Funded)

- No quality compromise (integrity of Data)
- Integrate site specific measurements constraints

Equipment Installation/deployment (Co-funded)

- On-site Supervision (SfP Team)
- Installation & access to infrastructures (End User)

Data collection (Co-funded)

- Data download (SfP Team)
- Access to infrastructures (End User)

Data Processing/Academia (Co-funded)

- Software design (SfP Participants)
- Equipment & Software purchases (SfP Funded)

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Ensuring Quality Wind Measurements

Duplicating Measurements
- Duplication of Calibrated Instruments
- Additional non-calibrated on-site instrument deployed
- Wind Measurements Vertical Profiling

Calibrated Instrumentation
- EU Standards
- Data used as collateral for Financing of Wind Parks
- Commercial value & End User interests

Develop Commercial Protocols for Data Processing
- Build expertise locally
- Wind data processing Services
- Wind Zoning and Mapping

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Small Wind Turbine Manufacturing Program

Identified Small Wind Turbine Technology (0,5 - 5 kW range)

- Design and reliability
- Quality of materials
- Costs

Visited Equipment Manufacturer

- Collaboration interests/potential
- Thorough Evaluation of local integration possibilities
- Design & construction (SWT parts)

Installation of wind turbines in test benches

Gain Expertise on Systems Integration (and Maintenance)

Deployment

- ✓Green Campus concepts (Al Akhawayn & Univ. of Nouakchott)
- ✓Telecom applications (Maroc Telecom / MAURITEL)
- ✓Rural electrification programs (ONE-PERG / APAUS)

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Small Wind Turbine Manufacturing Program

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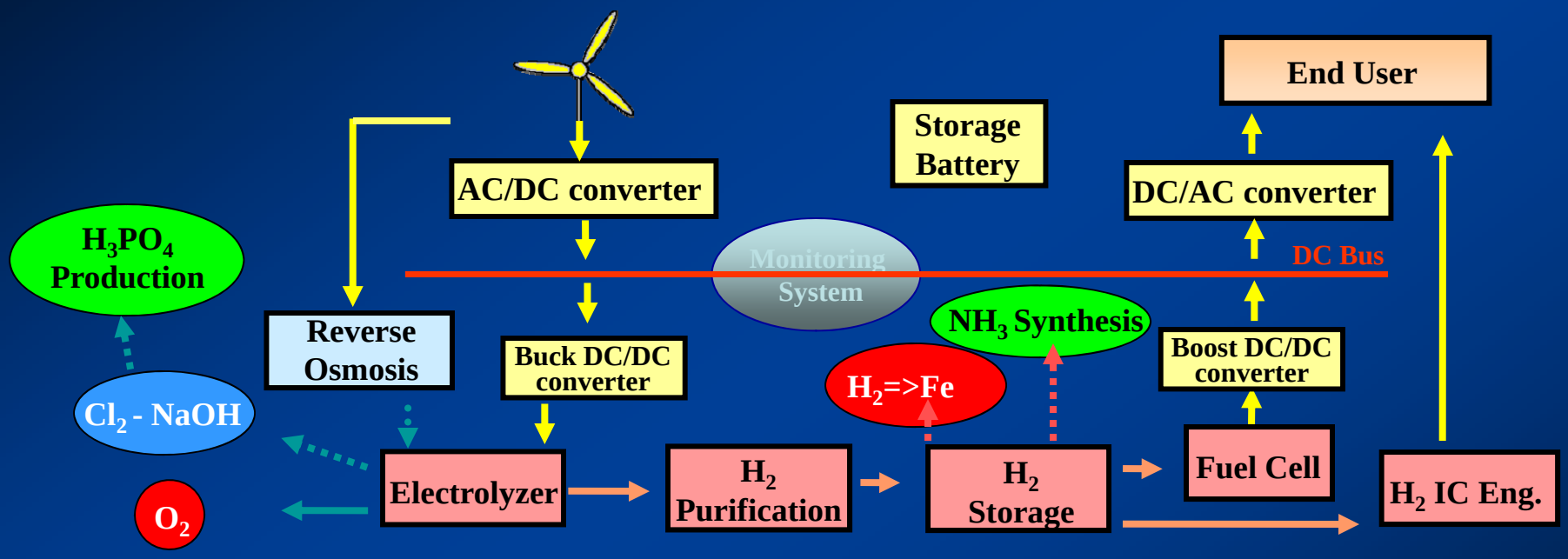
Electrolysis Test Benches



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Alkaline electrolyzer with pressurized output

Electrolyte: Potassium hydroxide

Power supply

20kW 3 Phase 400VAC

Controllable variable power range 7 – 20 kW

Operating pressure: 30 Bar.g

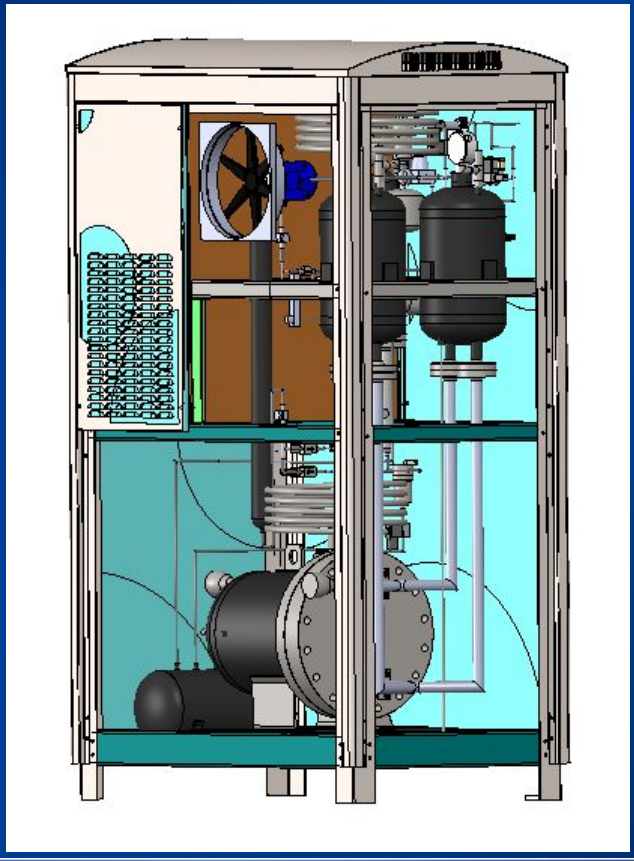
Rated production capacity (dry gas basis)

Hydrogen : 1.0-4.0 Nm3/h

Oxygen : 0.5-2.0 Nm3/h

Specific electrolysis power consumption

3.8-5.02 kWh/Nm3 of H2



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Alkaline electrolyzer with pressurized output

Automated system pressurized hydrogen and oxygen production.

Modular design with customizable solutions.

Applications for low, medium or high capacity requirements.

Systems tested in facilities prior to delivery.

Designed for manual and automatic, unattended continuous operation.

Automatic plant production control in the range 20 to 100%

Instrumentations for reliability and safety (directives, standard, certifications).

Electrode design with catalytic coating to reduce cell voltage, and specific energy consumption.

Low periodic inspection & maintenance requirements.

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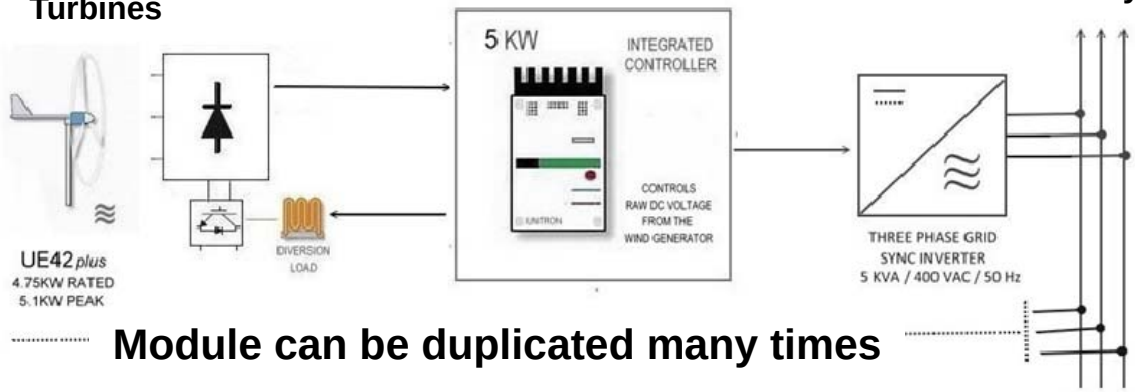
NATO SfP-982620 Test benches within Green Campus concepts

Small Wind Turbines

To Electrolyzer



Module can be duplicated many times

NOTES

1) The variable AC voltage from the wind generator is converted to DC, controlled with a band before feeding to inverter
2) The inverter will be current fed Grid sync type with three phase output
3) The inverter will feed power generated wind generator into three phase stabilised line that supports electrolyser

Local 3 Phase Power Supply 400 V AC 50hz

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NATO Science for Peace SfP-982620
Wind-Hydrogen Test Benches characteristics

5 kW Wind Turbine units locally assembled
1+5 units (Morocco) 2 + ? units (Mauritania)

20 kW Alkaline Electrolyzer (Pressurized output 30 bars)
Hydrogen purification
Hydrogen storage (48 Maxi cylinder packs)
Piping/Cabling
Control and Monitoring
Safety Multipoint Hydrogen Detection

1.2 kW Ballard Nexa Fuel Cell (back-up power)

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Sahara Wind Energy Development Project

Wind Energy integration & Alternative Energy Technologies

Capitalize on Industry and University/Research institutions

- Limited Size of Electricity Markets and Grid Infrastructures
- Reinforce Link with Industry (Largest Energy Consumers)
- Incubate, Test and Disseminate Technology (Clusters)
- Build Pilot Projects to Support Integrated Solutions

Wind-Hydrogen electrolysis provides an ideal testing ground for technological development of renewables and a hydrogen driven economy.

Non-Energy Local Hydrogen End User Market:
Morocco's Phosphate Industry, Mauritania's Iron Ore processing.

Sahara Wind's Upstream Project Development Activities to Pave Way to Large Scale Wind-HVDC Transfer and Wind-Hydrogen Applications.

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Electrolysis by-products and Hydrogen End-User Markets

Mauritania : Iron-Ore Industry (Alkaline Wind-Electrolysis)

- Hydrogen: Direct Iron Reduction process (DRI) 4% of World's primary iron production
- Electricity + Oxygen: Steel Production through Electric Arc Furnace (EAF) processes used in 45% of world steel production

Morocco: Phosphate Industry (Chlor-Alkali Wind Electrolysis)

- Hydrochloric acid for Phosphoric Acid Derivative Production processes
- Production of Ammonia (Stable H2 storage medium as well)
- Integrated fertilizer industry, beyond export of phosphate based fertilizers.
- Phosphor-gypsum recycling (12 Million tons/year currently dumped) transformable into Portland Cement (without any CO2 emissions).

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NATO Science for Peace SfP-982620 / UNIDO-ICHET Pilot Project Proposal
Integrated Electrolysis End-User Market Application

Wind speed: 8.5 m/s On-site (Measured through SfP-982620)
Wind-Electrolysis for Electricity, Oxygen and Hydrogen

Case Study: SNIM foundry (SAFA company)
Nouadhibou Installed Capacity: 15 MW + 18 MW (in 2010)
SAFA electricity needs: Electric Arc Furnace: 3 MW + Oxygen plant + Induction Ovens : 2 MW
Pilot Project:

- Wind Turbine(s)
- Alkaline Electrolyzer
- Hydrogen + Oxygen storage
- ICE-generator (backup power)

SAFA capacity (2 000 t) Local needs to supply construction iron, cast iron spares, fishing industry, etc.
Perspectives: 12~16 M.tons iron-ore annual exports can be processed into high value iron/steel products (CO2 free)
Current electricity costs: USD 22cent/kW.hr + Power Tax

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NATO Science for Peace SfP-982620 / UNIDO-ICHET Pilot Project Proposal
Integrated Electrolysis End-User Market Application

Wind speed: 7.5 m/s On-site (Measured through SfP-982620 in Tarfaya)
Wind-Electrolysis for Electricity, Hypochlorite and Hydrogen

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

- Small Wind Turbines
- Hypochlorite (Membrane) Electrolyzer
- Hydrogen storage
- Fuel Cell & ICE-generator

2- Tarfaya ONEP desalination plant

- Larger Wind Turbine(s)
- Hypochlorite (Membrane) Electrolyzer
- ICE-generator

Perspectives: Water treatment for Sahel regions
Water sanitation, Industry …

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ONEP

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Sahara Wind Energy Development Project

Wind-Hydrogen Electrolyzer distributed application

- Hypochlorite (Membrane) Electrolyzer (up to 100 kW range)

Produces Hydrogen, Hypochlorite, flexible power production, small scale

Drawback: Low Hydrogen output pressure

Electrocell Chlor-O-Safe™

Application areas:
Municipal water plants
Food processors
Industrial plants
Waste water treatment
Cooling towers
Power plants
Chemical Processes

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Sahara wind

Sahara Wind Energy Development Project

Wind-Hydrogen Electrolyzer larger application

- Chlor-Alkali Electrolyzer (MW Range)

Industrial scale Chlorine, Caustic Soda, and Hydrogen

Chlor -Alkali electrolyser at industrial plants (Source : Uhde GmbH)

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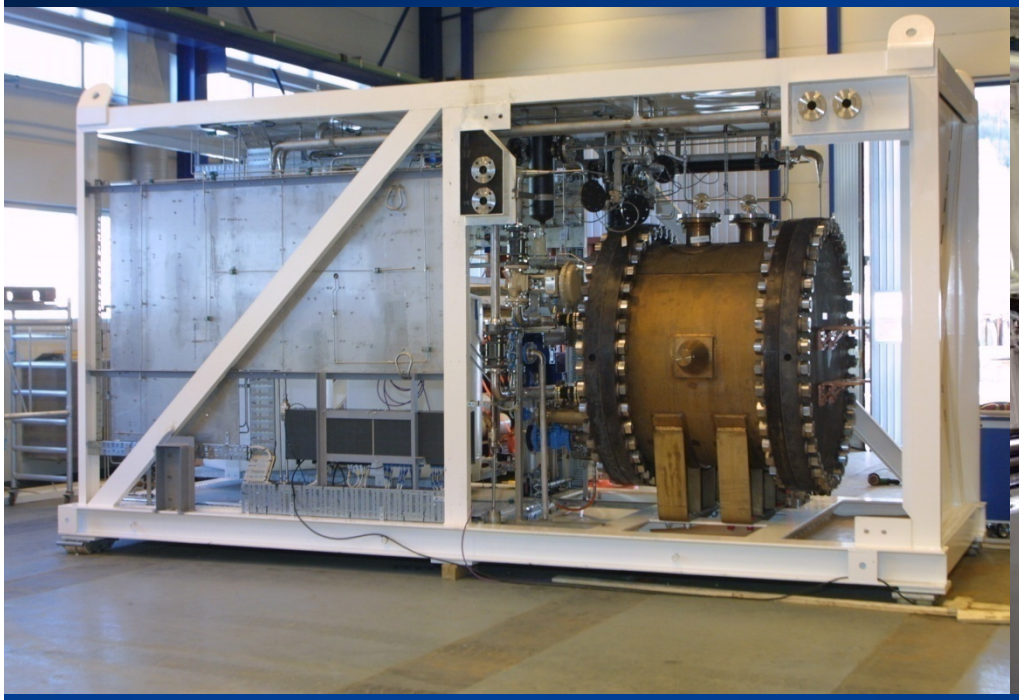
Sahara wind

Sahara Wind Energy Development Project

Wind-Hydrogen Electrolyzer larger application

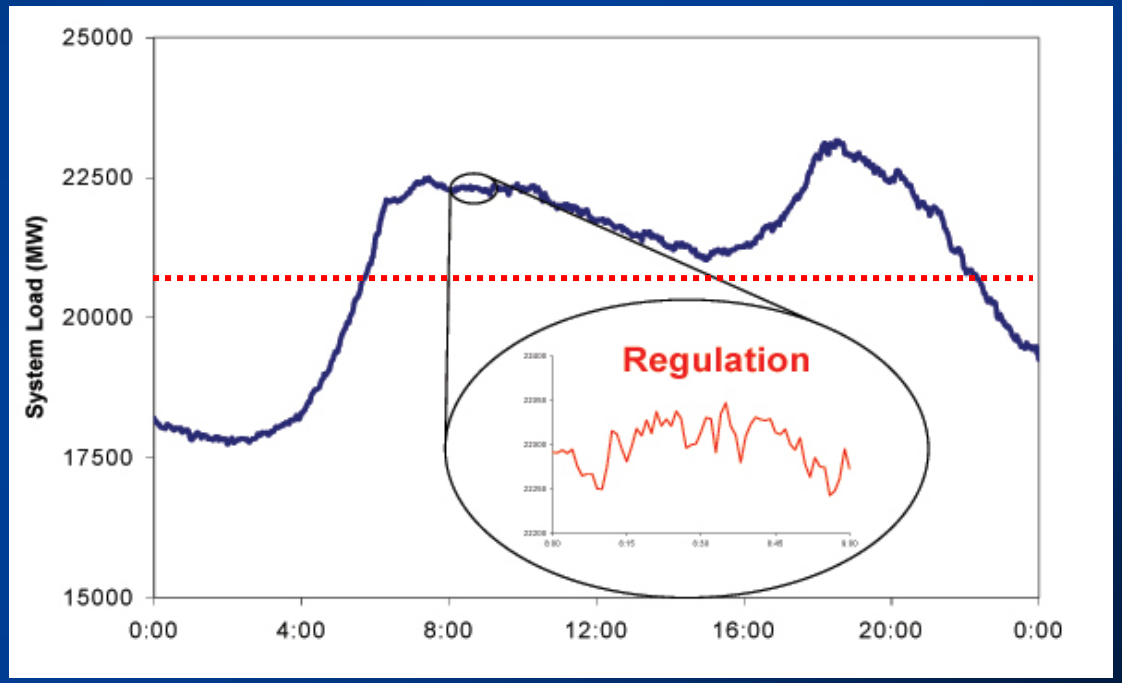


Norsk Hydro electrolyzer, KOH type 560 kW
130 Nm3 / hour at 450 psi (30 bar)
Photo: Norsk Hydro Electrolysers

Norsk Hydro Electrolyzers (2 MW)

Grid Stabilization through Wind-electrolysis

Wind power is erratic, power output fluctuates
Electrolyzers used as grid stabilizing 'dump loads'

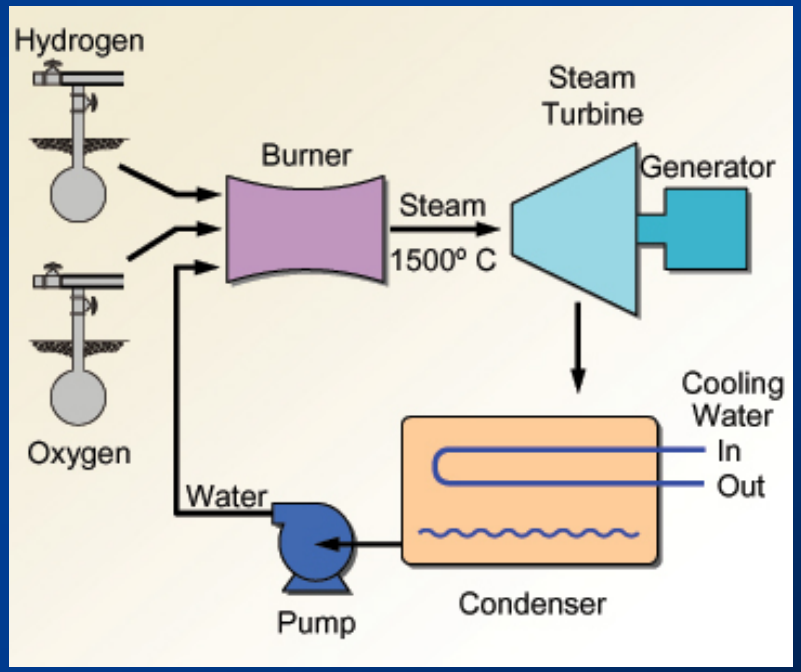


✓Eliminates wind fluctuation effects
✓Enhances power quality, flickers…
✓Frequency control

✓Generates H_2,O_2 … for grid stabilization & back up (spinning reserve), fuel (transport) or chemical feedstock's (industry).

Hydrogen-Oxygen Steam turbine

Special Steam turbine:
Converts H2 (Fuel) &
O2 (Oxidizer) mixture to Electricity



Used for Peak hours:
- Low investment costs
- Large units 50 MW
- High efficiency 70%
- Extremely fast response (ms)

Maximizing renewable energy uptake in weak grids
Wind-electrolysis for frequency control, peak power,
grid stabilization, spinning reserve, and back-up

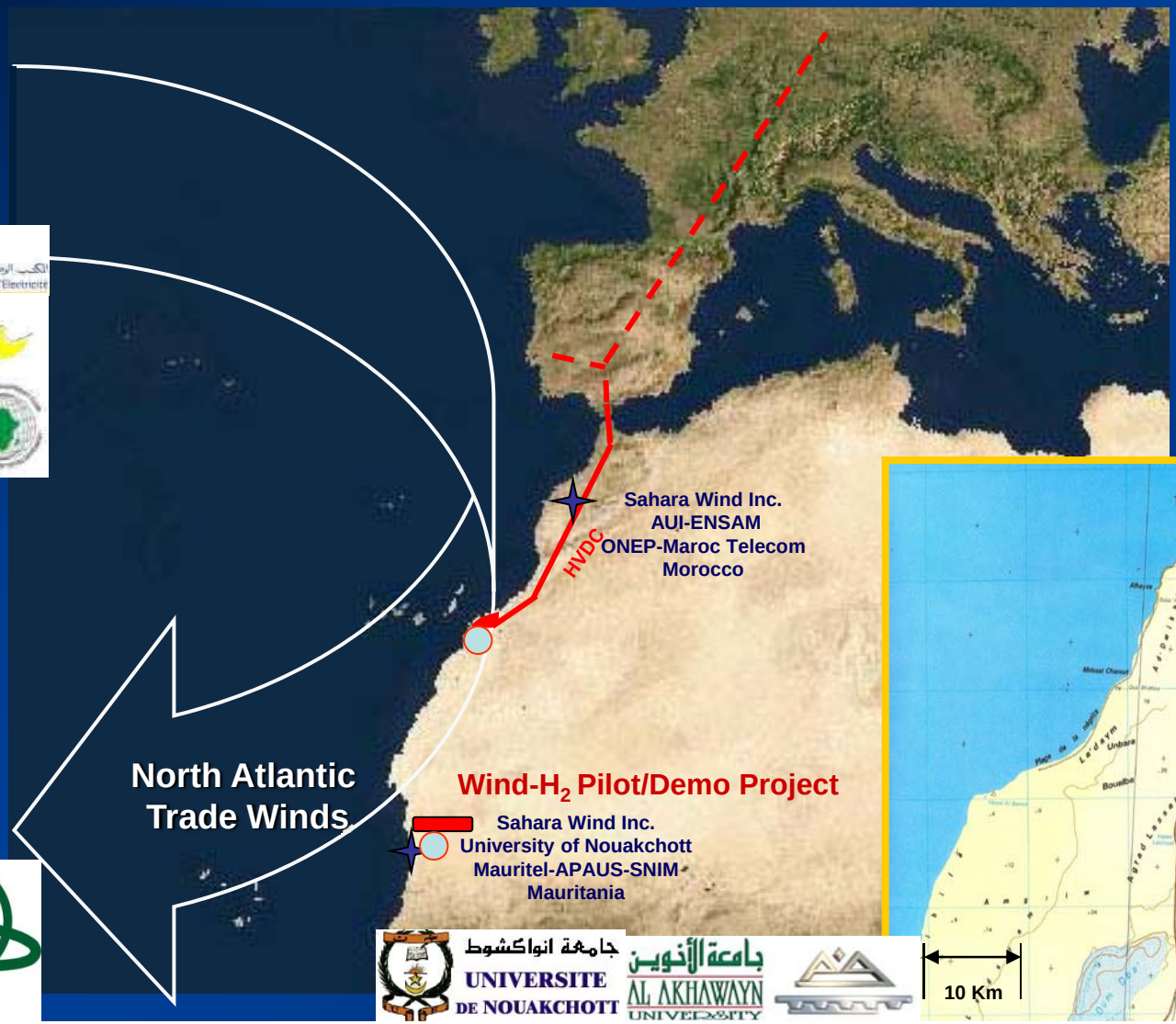
Sahara wind

NATO Science for Peace SfP-982620 UNIDO(ICHET) Sahara Wind-H_2 Demo Projects

Union for Mediterranean Solar Plan: 50 MW Sahara Wind Pilot Project

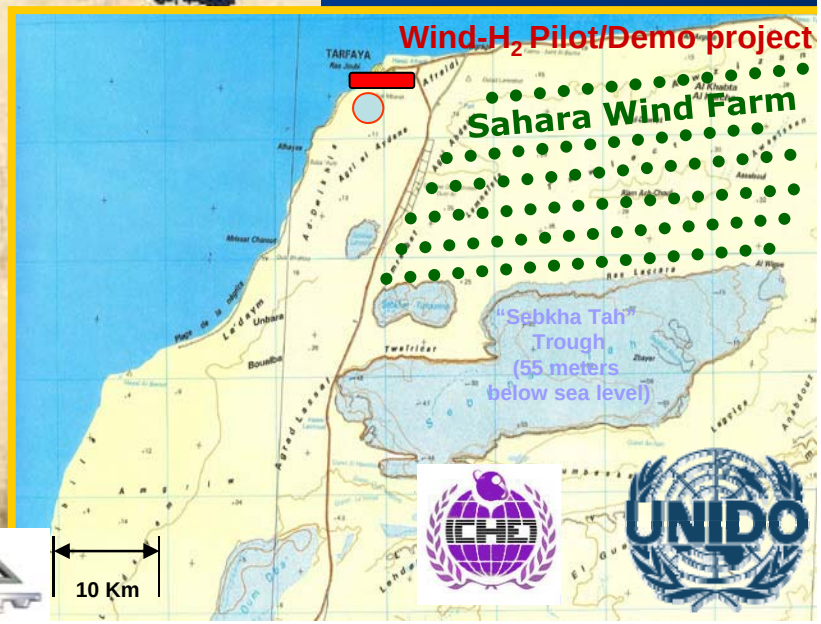
Morocco: Sahara Wind Phase I / Tarfaya (400-500 MW) 5~10 GW HVDC Extension

On-Grid Wind Electricity in a Liberalized Market: Joint WB-AfDB UNDP/GEF (PDF-B PIMS #3292)



H_2Storage

Wind Farm



GEF

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Sahara Wind Energy Development Project

Sahara Wind Phase 1: 50-500 MW on existing grid, impact study with ONE (Morocco utility) Initial Multilateral Support UfM Solar Plan, UNDP/GEF, WB, ADB, EBI…

Extensions through HVDC Technologies

Limited losses per kWh (4% over 1300 Km 500kV for 5000 MW)

Over 80 GW worldwide in 90 HVDC Projects: India, China, Canada, Brazil..

Euro-Mediterranean electricity market (Iberian) in full growth/expansion

Spain & Portugal (EU Members) ratified Kyoto Protocol

but Current CGH emissions 40~50% above Kyoto targets, highest in the EU

Impressive Wind catchment's area:

-Average wind speed: 8m/s (Trade Winds)

(measured at 9m height)

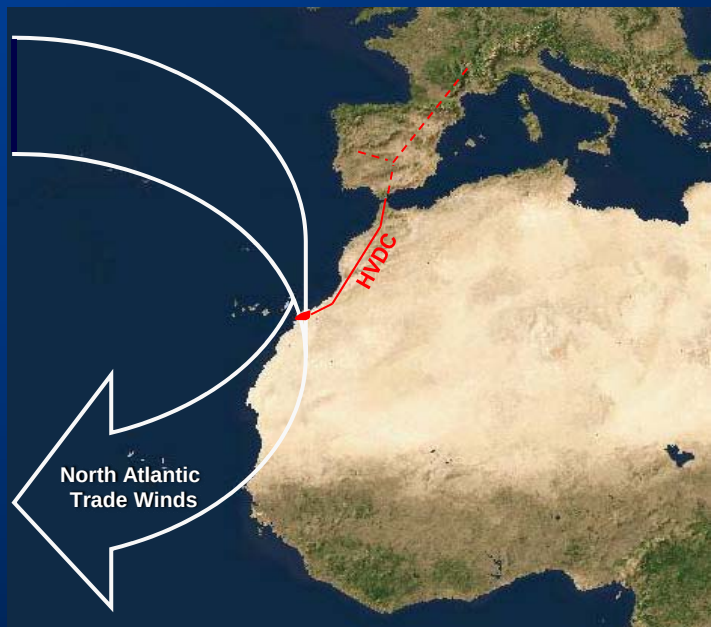
Higher Productivity compared to Europe

-Size of area (Saharan coast):

at least 2500 km length

(Morocco, Mauritania & Senegal)

- Potential Wind Energy 500~1000 GW(?)+



Sahara wind

SAHARA WIND ENERGY PROJECT
(under Solar Plan of Union for the Mediterranean)

Pilot Project: 50 MW-500 MW (2011-2014)
Installed capacity: 5 GW Wind Electricity (2015-2020)
Final Capacity: 10 GW Wind-Solar (beyond 2020)

HVDC Electricity TRANSFER CAPACITY: 10 GW (Cables)

- Substations initially for 5 GW before 2015 (doubled after 2020)
- Cable sizing: 10 GW
- Distance: 1500 km South of Morocco-Iberian peninsula & beyond within EU

5 GW Wind Energy: HVDC Technology (losses: 3% over 1500 Km ±500kV)
5 GW Solar or Solar/Wind Hybrid (HVDC Losses 5% over 1500 Km ±500kV)

Costs (1.3-1.5 Billion EUR) additional substations for Extensions 5GW (Morocco Solar Plan) Beyond 800 Km distance: HVDC only economically possible solution

Supplies Power below costs of Iberian market 4.5cent€/kWh
Economies of Scale and Phased Deployment Calendar

Sahara Wind Energy Development Project

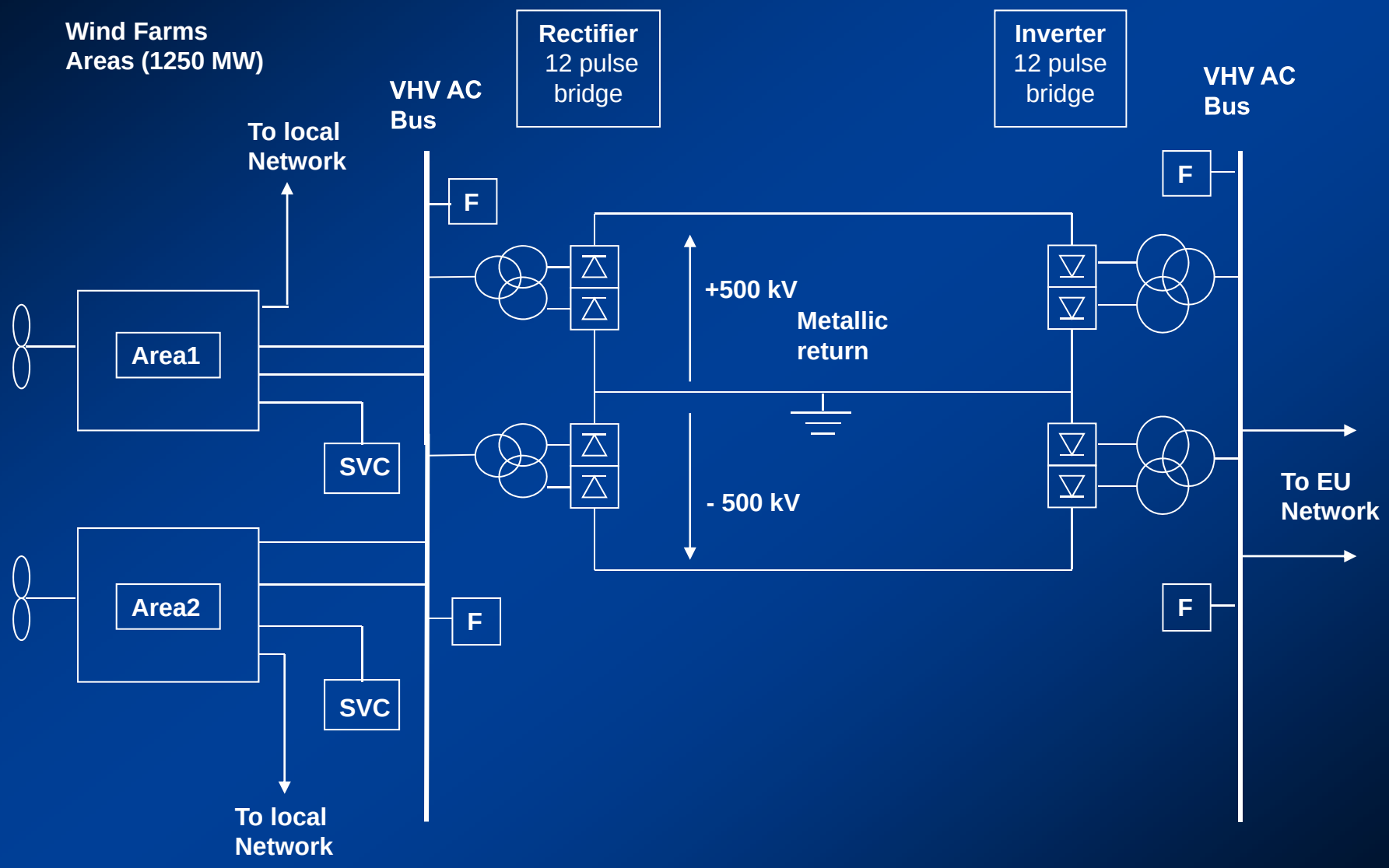
Electricity High Voltage Line technologies

High Voltage Direct Current (HVDC) *versus* High Voltage Alternating Current (HVAC)

Left: 3,000 MW HVDC (Pacific DC Intertie, PDCI) **Right: 300 MW HVAC**

Near Bishop, California USA

Figure 1 : Sahara Wind - HVDC Transmission Architecture - bipole 1



Sahara wind

Sahara Wind Project Deployment Strategy

Wind Energy, Capacity Building, Energy Access, Integrated Power System

The critical size of the Sahara Wind Project enables:

- Building a Broad Project Development Platform
- Involve Several Multilateral Institutions
- Leverage Capacity Building to Develop Long Term Strategy

NATO Science for Peace SfP 982620 project a first step into gradual introduction of state-of-the-art energy technologies.

Expand this platform into the Sahara/Sahel region

Bridge hydrogen production technologies and applied research with needs of developing countries.

Hydrogen green campuses coordinated by Sahara Wind Inc with NATO co-funding and demo/pilot Projects with UNIDO-ICHET co-funding could be listed under IPHE collaborative projects (involves several participating IPHE member countries).

IPHE World Hydrogen Project label:
Would Enable Transition from raw mineral extractive economy into local, value added carbon free sustainable processing industries (Based on Renewables & Hydrogen).

Saharawind

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