INTRODUCTION TO THE NEO-CARBON ENERGY PROJECT – HOW TO REACH A 100% RENEWABLE ENERGY SYSTEM

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Clean Disruption and Abundant Futures
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What is the Vision?

Neo-Carbon Energy: Future Energy System

Youtube link
Agenda

- Major Constraints for Energy Systems
- COP21 paving the way to survival
- Sustainability of Energy Scenarios
- Key enabling technologies
- Solutions: case Finland
- Solutions: global overview
- Solutions: Power-to-X / RE-based Desalination
- Summary
Constraint 1: Electricity (Energy) Demand

Global Demand Growth
2035: 35,000 TWh$_{el}$
~2050: 55,000 TWh$_{el}$
~2065: 90,000 TWh$_{el}$

source: IEA, 2009; IEA, 2011; Breyer Ch., 2012
Constraint 2: Climate Change – Economics failed

“Climate Change presents a unique challenge for economics: it is the greatest and widest-ranging market failure ever seen.”

N. Stern, Economics of Climate Change, 2006
Constraint 2: Climate Change – temperature rise
Constraint 2: Climate Change - Tipping Points

Key insights:
• switch of stable status at a specific tipping point
• temperature is mainly the driving force
• most major planetary changes expected close beyond 2°C temperature increase
• each single tipping element represents a historic disaster of unique impact
• reason for global 2°C target

source: Lenton, 2008
Constraint 2: Impact of Climate Change

Widespread impacts attributed to climate change based on the available scientific literature since the AR4

Polar Regions (Arctic and Antarctic)

North America

Europe

Asia

Central and South America

Africa

Australasia

Confidence in attribution to climate change

Very low  Low  Medium  High  Very high

Indicates confidence range

Physical systems

Observed impacts attributed to climate change for

Biological systems

Human and managed systems

+ Impacts identified based on availability of studies across a region

Outlined symbols = Minor contribution of climate change
Filled symbols = Major contribution of climate change

Source: IPCC, 2014. 5th AR – Synthesis Report
Constraint 3: Diminishing Energy Fuels

Peak of Oil, Gas, Coal and Uranium production within next 5 – 25 years (very likely)
Constraint 4: Energy Injustice

Global Access to Electricity Distribution

Source: Breyer Ch., Werner C., et al., 2011. Off-Grid Photovoltaic Applications in Regions of Low Electrification: High Demand, Fast Financial Amortization and Large Market Potential, 26th EU PVSEC
Constraint 5: Heavy metal emissions (cancer deaths)

Key insight:
- Heavy metal emissions causing severe health damage are a tremendous and costly global health issue.
- ~100,000 killed people globally per year (based on German results).
- ~400,000 killed people taking into account worse filter standards.
- Ontario in Canada decided to phase-out coal due to very high subsidies in the health system (twice as high as the value of power).

Constraint 6: Energy Subsidies

Key insights:
• global energy subsidies are almost fully allocated for fossil (and nuclear) fuels
• fossil fuel subsidies are as large as global expenditures for the health sector
• RE would grow much faster if harmful fossil-nuclear subsidies would be phased-out
Constraint 7: Managing System Complexity

source:

- total value chain (top)
- internal conversion processes (left)
- reasons for low efficiency and high costs
  - complex value chains
  - many energy conversion steps
Constraint 8: Ecological Footprint

Historic Collapse Pattern (Jared Diamond)
- Over Exploitation of Resources
- Climate Change Impact
- Non Adaptive Social Behaviour
- Military Conflicts
- Structural Change in Trade Routes

source: Wackernagel, 2010; WWF, 2014

our performance is excellent, unfortunately under the wrong sign

decarbonised power systems are desperately needed
**Agenda**

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Conference of the Parties
Twenty-first session
Paris, 30 November to 11 December 2015
Agenda item 4(b)
Durban Platform for Enhanced Action (decision 1/CP.17)
Adoption of a protocol, another legal instrument, or an agreed outcome with legal force under the Convention applicable to all Parties

ADOPTION OF THE PARIS AGREEMENT

Article 2

1. This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by:

(a) Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;

(b) Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production;

(c) Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.

Article 4

1. In order to achieve the long-term temperature goal set out in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties, and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty.
What does this mean?

Country pledges for 2030
First good News
Net zero and GHG Emissions

What produces negative emissions?
- Afforestation
- CCS? Are the deposits save – for millions of years?
- What’s more?
Power Plants of the World

source:
Farfan J. and Breyer Ch., 2016. Structural changes of global power generation capacity towards sustainability and the risk of stranded investments, submitted
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Criteria for Sustainable Energy Scenarios

Definition of Sustainability:

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

World Commission on Environment and Development, 1987

Major criteria for sustainable energy scenarios

• Energy resource base
• Climate change impact
• Societal cost
• Coverage of energy sectors
• Energy access for all
What are the real low carbon investments?

Wind, Solar and Nuclear Grid Connections in the World 2000–2013
(cumulated, in GWe)

PV capacity expectations and role of IEA

Key insights:
- leading reports show at least 2-4 times higher numbers than IEA WEO for 2030 and 2040
- IEA WEO is lagging behind due to assuming wrong growth
- Greenpeace and BNEF had been close to real numbers in the past 10 years
- forecasts of fossil fuel companies such as Shell, BP and ExxonMobil are as conservative as the IEA WEO

<table>
<thead>
<tr>
<th>Year</th>
<th>IEA WEO</th>
<th>Greenpeace, BNEF</th>
<th>2DS hi-Ren</th>
<th>NPS</th>
<th>Source</th>
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<td>2030</td>
<td>1799 GW</td>
<td>2839 GW</td>
<td>1721 GW</td>
<td>728 GW</td>
<td>EWG, 2015. IEA creates misleading scenarios for solar power generation, press release, November 27</td>
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<td>2040</td>
<td>3687 GW</td>
<td>4988 GW</td>
<td>3199 GW</td>
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<td>3277 GW</td>
<td>1519 GW</td>
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</table>
Overview, Global Energy Scenarios

Key insights and general remarks:
• climate change as a major challenge accepted by all energy scenarios (lagging behind: Exxon)
• increasing share of RE is accepted by all scenarios (lagging behind: Exxon)
• assumptions of future energy demand and energy efficiency efforts differ widely
• NO scenario discusses impact of peak-oil, -gas, -coal and -uranium and respective price impacts
• dominance of power sector in future only understood by WWF and Greenpeace
• cost advantage of solar PV vs CSP reflected only by IEA-PVPS
• role of storage and long distance grids reflected by NO scenario
• power-to-gas technology as storage and bridging technology reflected by NO scenario
• coupling of energy sectors reflected by WWF, Greenpeace, IEA-PVPS but no cost transparency
• progressive: Greenpeace, WWF, WBGU
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Resources and Energy Demand

Key insights:
- no lack of energy resources
- limited conventional resources
- solar and wind resources need to be the major pillars of a sustainable energy supply

Remark:
- conventional resources might be lower than depicted by Perez

Solar Photovoltaics

Key insights:
- Accessible everywhere – no resource conflicts
- Highly modular technology – off-grid, distributed roofs, large-scale
- High learning rate due to 'simple' technology
- Efficiency limit 86%, best lab efficiency 46%, best in markets ~20%
- High growth rate - >40% last 20 years – fast cost decline
- Least cost electricity source in a fast growing number of regions
- 1st key enabling technology for survival of human civilization
Wind energy

Key insights:
• Accessible in all world regions – no resource conflicts
• Modular technology – off-grid, community turbines, large-scale
• Already on low cost level – 3 – 8 €ct/kWh
• Least cost electricity source in wind resource rich areas
• High full load hours due to 24/7 harvesting
• 2nd key enabling technology for survival of human civilization
Key insights:

• Batteries convert PV into flexible 24/7 technology
• Batteries show same high learning rates as PV
• Highly module technology – phone to storage plant
• Extreme fast mobility revolution (fusion of renewables, modularity, digitalization, less complex)
• High growth rates – fast cost decline
• Least cost mobility solution from 2025 onwards
• Key reason for collapse of western oil majors
• 3rd key enabling technology for survival of humankind
Power-to-X – covering hydrocarbon demand

Key insights:
- PtX enables sustainable production of hydrocarbons
- Ingredients: electricity, water, air
- w/o PtX COP21 agreement would be wishful thinking
- Profitability from 2030 onwards
- Flexibal seasonal storage option
- Global hydrocarbon downstream infrastructure usable
- Most difficult sectors to decarbonise can be managed with PtX (aviation, chemistry, agriculture, etc.)
- 4th key enabling technology for survival of humankind
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Flows of energy – Basic 100% RE scenario

Total annual costs

Key insights:
• Despite overall costs being somewhat similar for test scenarios, 100% RE scenarios have less exposure to risks of higher costs related to WACC and carbon emissions

* WACC 7% ► 15%
BAU: + 3 b€
New Nuclear: + 2 b€

** CO₂ price 75 ► 150 €/t
BAU: + 1.9 b€

Annual production and consumption data

Key insights:
- Seasonality of solar PV is complemented somewhat by wind power generation.
- CHP generation in colder months also complements solar PV.
- Storage technologies add considerable flexibility to the system.
Storage state of charge

Child et al., “The role of solar photovoltaics and energy storage solutions in a 100% renewable energy system for Finland in 2050,” in EU PVSEC, Hamburg, Sept. 14-18, 2015

Key insights:

- Only 5 full load cycles for stationary batteries and 129 for V2G batteries
  - Contrary to other model results (200-300 cycles)
- Thermal energy storage levels high during summer months
- High use of grid gas storage
- Greatest flexibility comes from gas storage
- Daily storage with V2G plus seasonal storage with Gas and TES
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Key Objective

Definition of an optimally structured energy system based on 100% RE supply

• optimal set of technologies, best adapted to the availability of the regions’ resources,
• optimal mix of capacities for all technologies and every sub-region of Eurasia,
• optimal operation modes for every element of the energy system,
• least cost energy supply for the given constraints.

LUT Energy model, key features

• linear optimization model
• hourly resolution
• multi-node approach
• flexibility and expandability

Input data

• historical weather data for: solar irradiation, wind speed and hydro precipitation
• available sustainable resources for biomass and geothermal energy
• synthesized power load data
• gas and water desalination demand
• efficiency/ yield characteristics of RE plants
• efficiency of energy conversion processes
• capex, opex, lifetime for all energy resources
• min and max capacity limits for all RE resources
• nodes and interconnections configuration
Methodology

Full system

Renewable energy sources
- PV rooftop
- PV ground-mounted
- PV single-axis tracking
- Wind onshore/offshore
- Hydro run-of-river
- Hydro dam
- Geothermal energy
- CSP
- Waste-to-energy
- Biogas
- Biomass

Electricity transmission
- node-internal AC transmission
- interconnected by HVDC lines

Storage options
- Batteries
- Pumped hydro storage
- Adiabatic compressed air storage
- Thermal energy storage, Power-to-Heat
- Gas storage based on Power-to-Gas
  - Water electrolysis
  - Methanation
  - CO$_2$ from air
  - Gas storage

Energy Demand
- Electricity
- Water Desalination
- Industrial Gas
Results: Europe
Regions Electricity Capacities – area-wide open trade

Area-wide open trade

Key insights:
• Area-wide scenario shows small share of system PV capacities in most of the regions, prosumer share is significant
• Sunny conditions in Iberia lead to significant share of PV single-axis
• >50% wind share in Baltic, Denmark, British Isles, France, Poland, Ukraine

Area-wide open trade desalination gas

Key insights:
• PV plays a major role in Area-wide desalination gas scenario for Central and Southern Europe
• PV single-axis and wind are the main sources of electricity for water desalination and industrial gas production
• resistance against new grids could drastically increase the PV share
Results: Europe
Storages Capacities – area-wide and area-wide open trade desalination gas

Area-wide open trade

Area-wide open trade desalination gas

Key insights:
• Excess energy for area-wide open trade desalination gas lower than with independent sectors (from 141 TWh to 132 TWh, also relative shares of excess energy decrease from 3.2% to 2.2% of total generation).
• Existing PHS storages play significant role
• Relative share of prosumers’ batteries increases significantly in integration scenario in Northern Europe
• Absolute storage capacities increase in Southern Europe and decrease in Central and Northern Europe when sectors are integrated
Results

The MENA Region Electricity Capacities

Area-wide open trade

Key insights:
- Area-wide scenario shows a high share of PV single-axis and wind energy capacities in most of the regions, prosumers share is significant
- Sunny conditions in most of the regions lead to significant share of PV single-axis
- The highest share of wind energy in North African regions, Saudi Arabia, Yemen, Oman, Syria, Iran, Jordan and Iraq

Area-wide open trade desalination gas

Key insights:
- Installed capacities for PV and wind increase significantly by 390% and 293% compared to the area-wide scenario
- PV plays a major role in Area-wide desalination gas scenario for Israel, UAE, Bahrain, Qatar and Yemen, Oman
- PV single-axis and wind are the main sources of electricity for water desalination and industrial gas production
- resistance against new grids could drastically increase the PV share

Recent examples of wind/ PV cost in MENA

Wind onshore

Morocco
Wind onshore
tender signed 2016-01
price: 3.0 USD/kWh

PV utility-scale

UAE - Dubai
PV utility-scale
tender confirmed 2016-05
price: 2.99 USD/kWh
Results
Net exporter region – North-West Russia

source: Bogdanov D. and Breyer Ch., 2015. Eurasian Super Grid for 100% Renewable Energy power supply: Generation and storage technologies in the cost optimal Mix
Results
Balancing region – Northwest China

source: Bogdanov D. and Breyer Ch., 2016. North-East Asian Super Grid for 100% Renewable Energy supply: Optimal mix of energy technologies for electricity, gas and heat supply options, Energy Conversion and Management, 112, 176-190
Results

Net exporter region – India East

Key insights:
- India East exports 6 TWh of electricity, i.e. the region is mainly a self-supplying region
- Energy mix is mainly based on PV plus some hydro dams and biomass
- Batteries shift PV based electricity in the afternoon and night
- Flexible biomass and hydro are used in evening and night hours

source: Gulagi A., et al., 2015. Electricity system based on 100% Renewable Energy for India and SAARC
Results
Net exporter region – India West (monsoon month)

Key insights:
• India West exports 22 TWh of electricity to the grid (neighbouring regions)
• Energy mix is mainly based on PV, wind, hydro dams and biomass
• Monsoon month shows reduced solar resource but increased wind
• Batteries shift PV based electricity in the afternoon and night
• Batteries support grid exports and continuous PtG operation in night hours

source: Gulagi A., et al., 2015. Electricity system based on 100% Renewable Energy for India and SAARC
Results
Net importer region - Venezuela

source: Barbosa L., et al. 2015. Complementarity of hydro, wind and solar power as a base for a 100% RE energy supply: South America as an example
# Overview on World’s Regions

<table>
<thead>
<tr>
<th>Regions</th>
<th>LCOE region-wide [€/MWh]</th>
<th>LCOE area-wide [€/MWh]</th>
<th>Integraton benefit ** [%]</th>
<th>storage [%]</th>
<th>grids regions' trade [%]</th>
<th>Curtailment [%]</th>
<th>PV prosumers [%]</th>
<th>PV system [%]</th>
<th>Wind [%]</th>
<th>Biomass [%]</th>
<th>Hydro [%]</th>
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<tr>
<td>Northeast Asia</td>
<td>66</td>
<td>56</td>
<td>6.0%</td>
<td>7%</td>
<td>10%</td>
<td>5%</td>
<td>16.4%</td>
<td>35.4%</td>
<td>40.9%</td>
<td>2.9%</td>
<td>11.6%</td>
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<tr>
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<td>8%</td>
<td>3%</td>
<td>3%</td>
<td>7.2%</td>
<td>36.8%</td>
<td>22.0%</td>
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<tr>
<td>India/ SAARC</td>
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<td>67</td>
<td>5.9%</td>
<td>22%</td>
<td>23%</td>
<td>3%</td>
<td>6.2%</td>
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<td>Eurasia</td>
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<td>53</td>
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<td>&lt;1%</td>
<td>13%</td>
<td>3%</td>
<td>3.8%</td>
<td>9.9%</td>
<td>58.1%</td>
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<td>6%</td>
<td>17%</td>
<td>2%</td>
<td>12.3%</td>
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<tr>
<td>MENA</td>
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<td>&lt;1%</td>
<td>10%</td>
<td>5%</td>
<td>1.8%</td>
<td>46.4%</td>
<td>48.4%</td>
<td>1.3%</td>
<td>1.1%</td>
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<td>Sub-Saharan Africa</td>
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<td>8%</td>
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<td>28.0%</td>
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**Key insights:**

- 100% RE is highly competitive
- least cost for high match of seasonal supply and demand
- PV share typically around 40% (range 14-50%)
- hydro and biomass limited the more sectors are integrated
- flexibility options limit storage to 10% and it will further decrease with heat and mobility sector integration
- most generation locally within sub-regions (grids 3-23%)
Demand for solar PV (2030, integrated)

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<td>1813</td>
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<td>268</td>
<td>496</td>
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<td><strong>total</strong></td>
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<td><strong>37586</strong></td>
<td><strong>2989</strong></td>
<td><strong>6807</strong></td>
<td><strong>9795</strong></td>
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<td>world as of total</td>
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<td>31%</td>
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<td></td>
<td>87%</td>
<td>72%</td>
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Source: Breyer Ch., 2016. First Insights on the Role of solar PV in a 100% Renewable Energy Environment based on hourly Modeling for all Regions globally, Global Photovoltaic Conference, Daequ, April 6
Hybrid PV-Battery-GT Plant (hourly)

Hybrid Photovoltaic (PV) power plant:
- PV single-axis tracking system
- Lithium-ion batteries
- gas turbine (OCGT)

Coal-fired power plant:
- boiler
- steam turbine

Open cycle gas turbine power plant:
- gas turbine

Combined cycle gas turbine power plant:
- steam turbine
- gas turbine

source: Afanasyeva S., Breyer Ch., Engelhard M., 2016. The Impact of Cost Dynamics of Lithium-Ion Batteries on the Economics of Hybrid PV-Battery-GT Plants and the Consequences for Competitiveness of Coal and Natural Gas-Fired Power Plants, 10th IRES, Düsseldorf, March 15-17
Key insights:

- Results indicate advantage for hybrid PV-Battery-GT plant in Morocco in 2030
- Future battery cost development is the major unknown factor
- Implemented battery cost for power/energy 2020: 150/300; 2030: 100/150 per kW/kWh

Source: Afanasyeva S., Breyer Ch., Engelhard M., 2016. The Impact of Cost Dynamics of Lithium-Ion Batteries on the Economics of Hybrid PV-Battery-GT Plants and the Consequences for Competitiveness of Coal and Natural Gas-Fired Power Plants, 10th IRES, Düsseldorf, March 15-17
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RE-PtG-LNG Value Chain

Hybrid PV-Wind & Battery  Power-to-Gas  SNG Liquefaction  LNG Shipping  LNG Regasification

Key insights:
• Substitution of the fossil hydrocarbon value chain by a RE basis
• Utilization of downstream fossil infrastructure
• Integrated heating system
• Water recycling

source: Fasihi M., Bogdanov D., Breyer Ch., 2015. Economics of global LNG trading based on hybrid PV-Wind power plants, 31st EU PVSEC, Hamburg, September 14-18
Methodology
RE-PtG-LNG Value Chain

Key insights:
- Substitution of the fossil hydrocarbon value chain by a RE basis
- Utilization of downstream fossil infrastructure
- Integrated heating system
- Water recycling

source: Fasihi M., Bogdanov D., Breyer Ch., 2015. Economics of global LNG trading based on hybrid PV-Wind power plants, 31st EU PVSEC, Hamburg, September 14-18
Data
Plants’ Location

1) Patagonia, Argentina:
   • Hybrid PV-Wind Power Plant
   • PtG Plant
   • Liquefaction Plant

2) Japan:
   • Regasification Plant

Marine distance
   • Patagonia – Japan: 17,500 km
   • Patagonia – Hamburg: 14,000 km

source: Fasihi M., Bogdanov D., Breyer Ch., 2015. Economics of global LNG trading based on hybrid PV-Wind power plants, 31st EU PVSEC, Hamburg, September 14-18
Results
RE-PtG-LNG Value Chain - Energy & Mass Flow

- System integration benefits:
  - 87% of energy needed for CO\textsubscript{2} capture plant is coming from excess heat
  - 48% of electrolyzer’s water demand coming out of methanation

- Heat exchanger eff.: 90%
- LNG value chain eff.: 89%
- Electrolyzer, the main electricity consumer
- Oxygen available for potential market

\textbullet Overall efficiency: 58%

source: Fasihi M., Bogdanov D., Breyer Ch., 2015. Economics of global LNG trading based on hybrid PV-Wind power plants, 31st EU PVSEC, Hamburg, September 14-18

*LT: low temperature
**HT: high temperature
Results
RE-PtL Value Chain - Energy & Mass Flow

- Electrolyzer, the main electricity consumer
- FT the main source of energy for the CO₂ capture plant
- Oxygen available for potential market
- H₂tL eff.: 71.8 %
- Heat exchanger eff.: 90%
- Heat loss: 4.2%

❖ Overall efficiency: 57.5%

87% of energy demand supplied by excess heat
63% of water demand supplied by RWGS and FT process output

source: Fasihi M., Bogdanov D., Breyer Ch., 2016. Techno-economic Assessment of Power-to-Liquids (PtL) Fuels Production and Global Trading Based on Hybrid PV-Wind Power Plants, 10th IRES, Düsseldorf, March 15-17
Synthetic renewable fuels - Summary

- 70 €/MWh\(_{\text{fuel}}\) equals 0.68 €/l
- 55 €/MWh\(_{\text{fuel}}\) equals 0.53 €/l
RE-based synfuels future business case for Iran

Key insights:

- COP21 agreement will phase-out business of oil/gas exporting countries
- Solar and wind resources rich countries can offer new products to their customers on a net zero emissions basis
- Iran and phase-in sustainable hydrocarbon products using existing infrastructure
- Open-minded countries may take the most advantages from the new options

Clean water for all: RE-based desalination

Overview:
- clean water for all (and nearly everywhere) is no wishful thinking
- water crisis is rather a management failure than a techno-economic issue
- basis for sustainable CCS

source: Caldera U., Bogdanov D., Breyer Ch., 2016. Local cost of seawater RO desalination based on solar PV and wind energy - A global estimate, Desalination, 385, 207-216
Agenda

- Major Constraints for Energy Systems
- COP21 paving the way to survival
- Sustainability of Energy Scenarios
- Key enabling technologies
- Solutions: case Finland
- Solutions: global overview
- Solutions: Power-to-X / RE-based Desalination
- Summary
Summary

- Tremendous energy-related global problems induce collapse of global civilization – without drastic and fast change of our energy basis
- COP21 agreement in Paris is the first real attempt for survival of civilization
- Net zero emissions is equal to phase-out of all fossil fuels by 2050
- Global energy scenarios are of poor quality, except Greenpeace Energy R[e]volution
- Sustainable resource basis is excellent
- Key enabling technologies are solar PV, wind energy, batteries, PtX
- 100% renewable energy system is a low cost solution
- COP21 and 100% renewables create the largest business opportunity ever
- Major survival barrier: slow, in flexible and lobbyism-stressed politics
Thank you for your attention … … and to the team!

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