The Changing Energy System
Keynote Introduction

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Renewable Energy and Hydrogen Export, International Workshop
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Contents

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1 About LBST

1 Ludwig-Bölkow-Systemtechnik GmbH (LBST)

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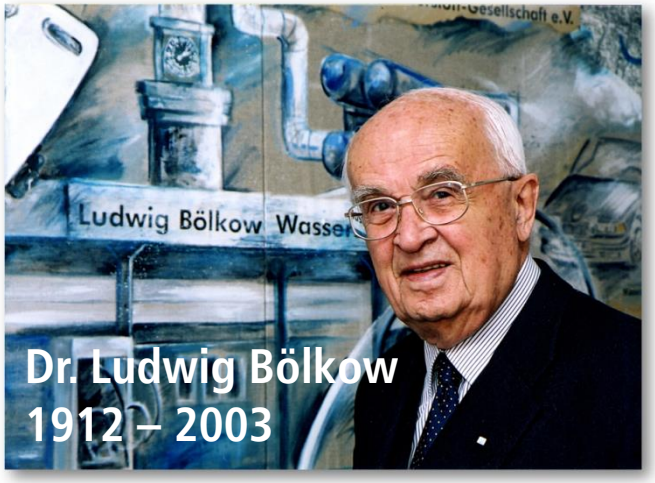
Securing your sustainable decisions.



- Independent experts for sustainable energy and mobility since almost 30 years
- Renewable energies, fuels, hydrogen, infrastructure
- Feasibility and sustainability studies, technology based strategic consulting, energy concepts
- Rigorous systems approach – thinking beyond sectoral borders

2 Global Challenges

2 World Urbanization

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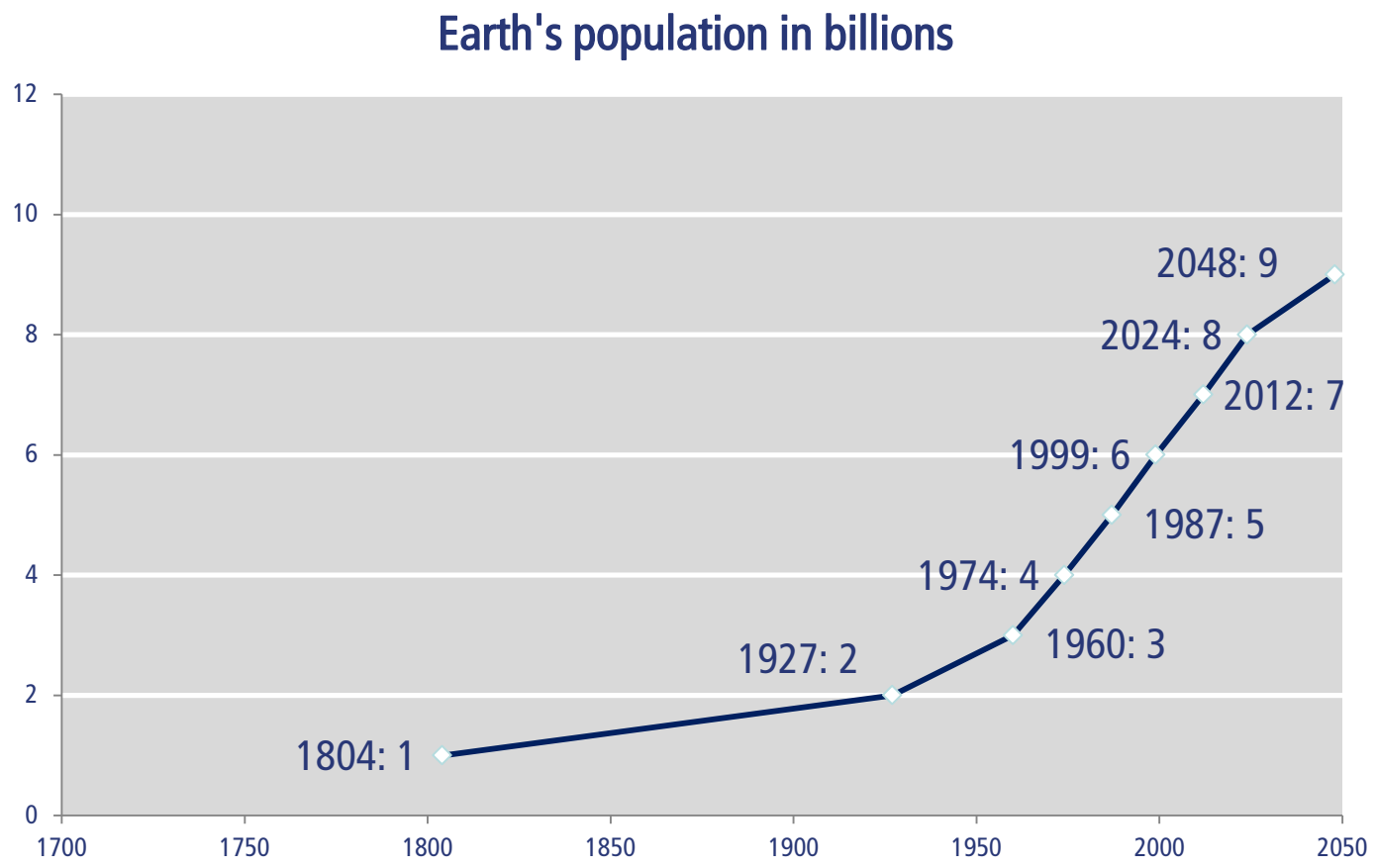

Source: LBST, 2013 based on www.allianz.com, UN data and University of Pennsylvania, 2012

2 Development of Atmospheric CO_2 Concentration

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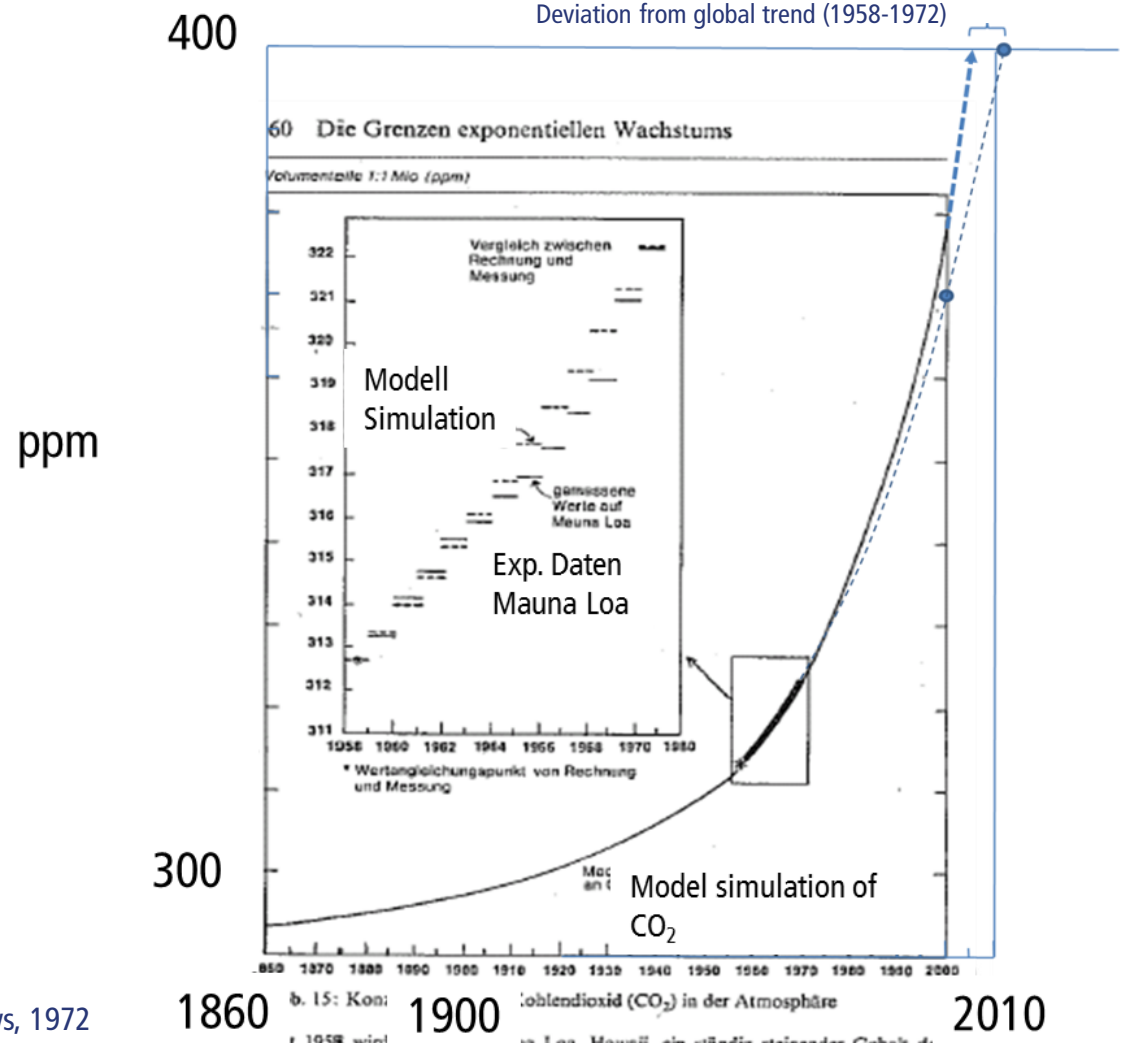
Success of Climate Policy?

Deviation from global trend (1958-1972)



Source: LBST, 2014, based on Meadows, 1972

2 Global Average World Temperature Change by Regions

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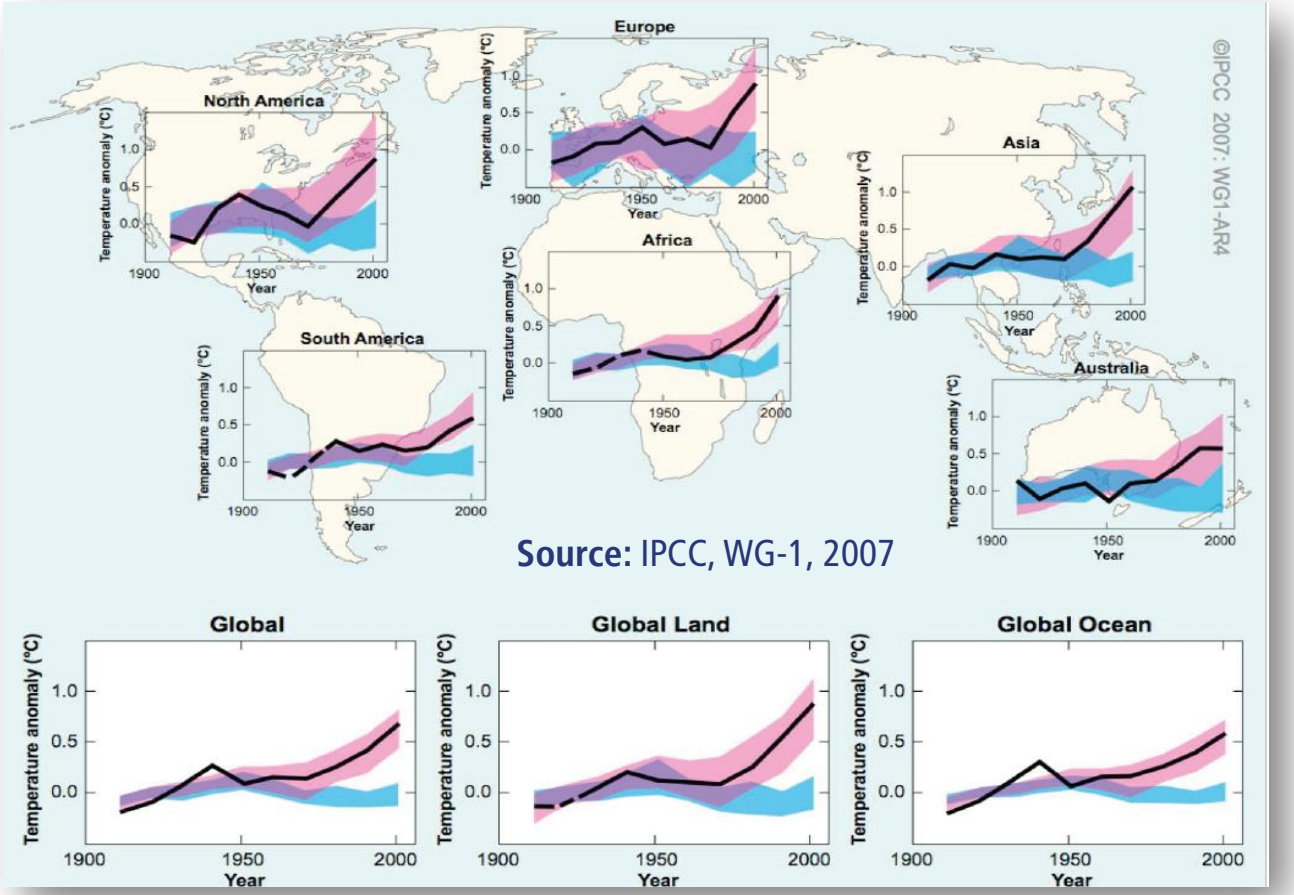
- **Clear evidence:**
  World regions' average temperature rise modelled with / without CO_2 emissions



Source: IPCC, WG-1, 2007

— Measured T

With CO_2-emissions

Without CO_2-emissions

Source: IPCC, 2012

2 World Oil Production at Its Peak

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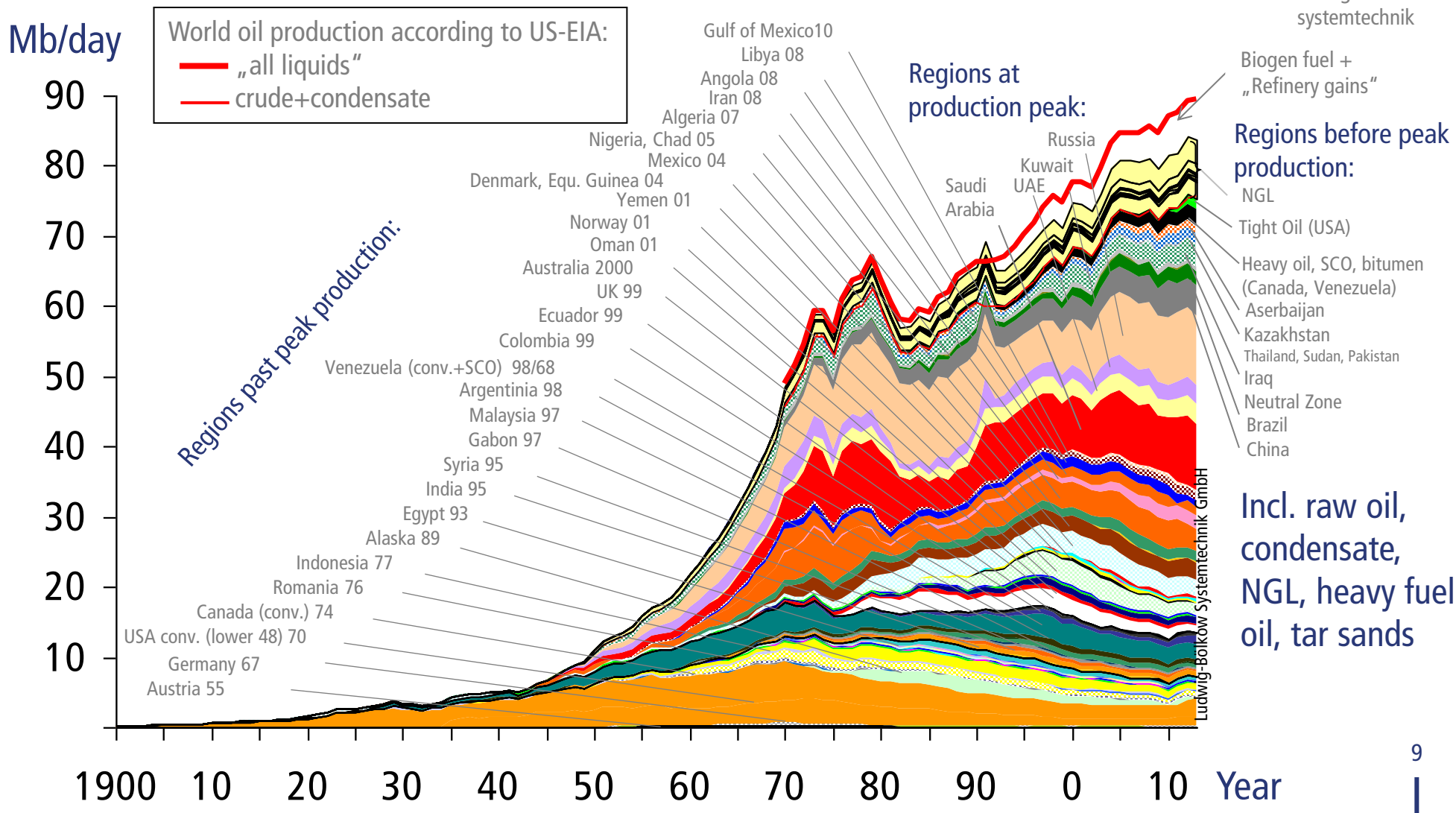

Incl. raw oil, condensate, NGL, heavy fuel oil, tar sands

Source: LBST, FEB 2014 based on Austria, Germany, USA, Canada, Netherlands, UK, Norway, Denmark, Saudi Arabia, Brazil, Mexico: national state or state company statistics; For other countries US-EIA, since 1970; 2013 extrapolated from Jan-Jul, historical data until 1970 (for some States until 2005): IHS-Energy 2006

2 World Oil Supply – A Perspective

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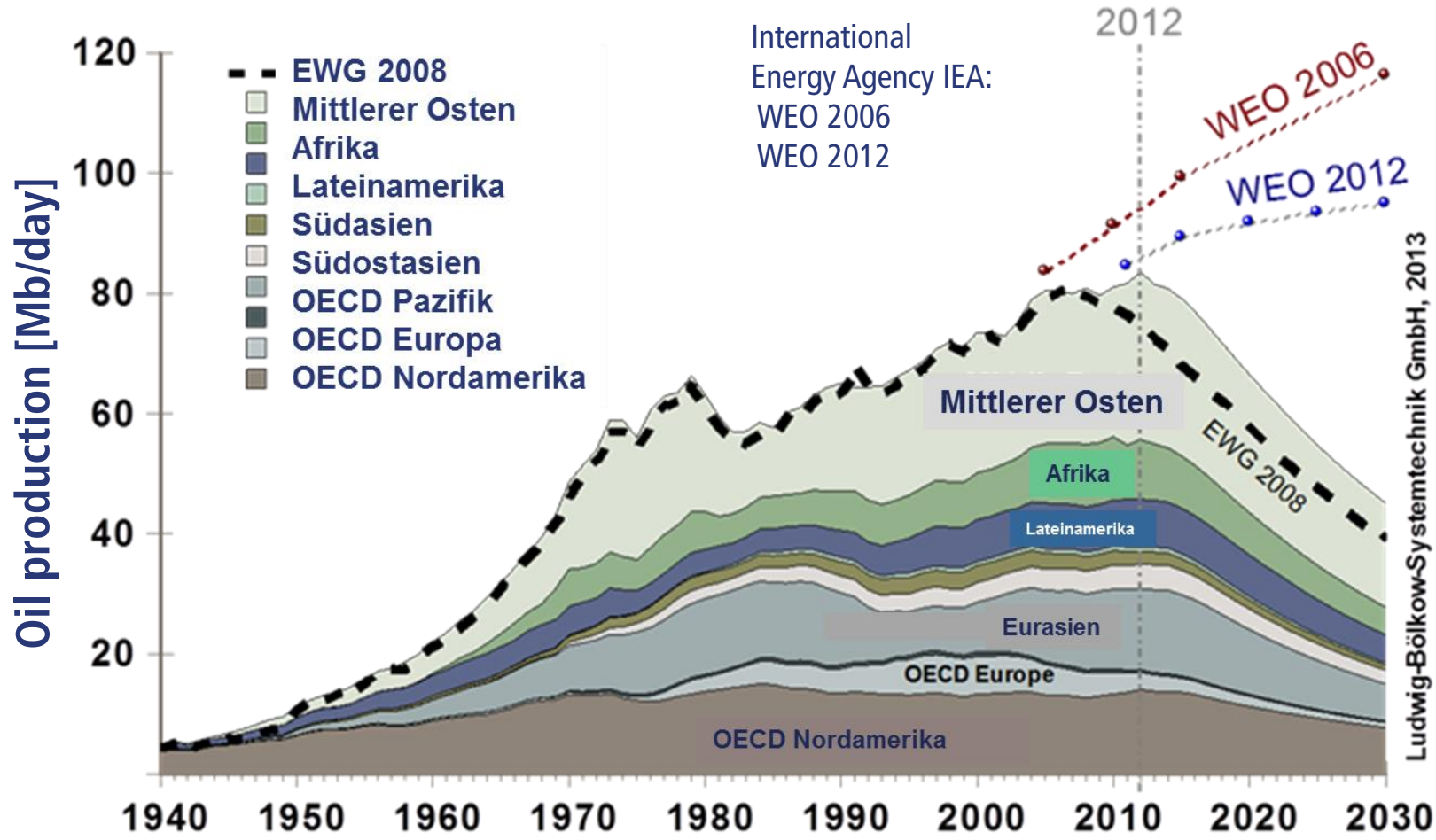

Source: Energy Watch Group 2008, 2013; IEA 2006, 2012

2 The Petroleum Age – Which Age?

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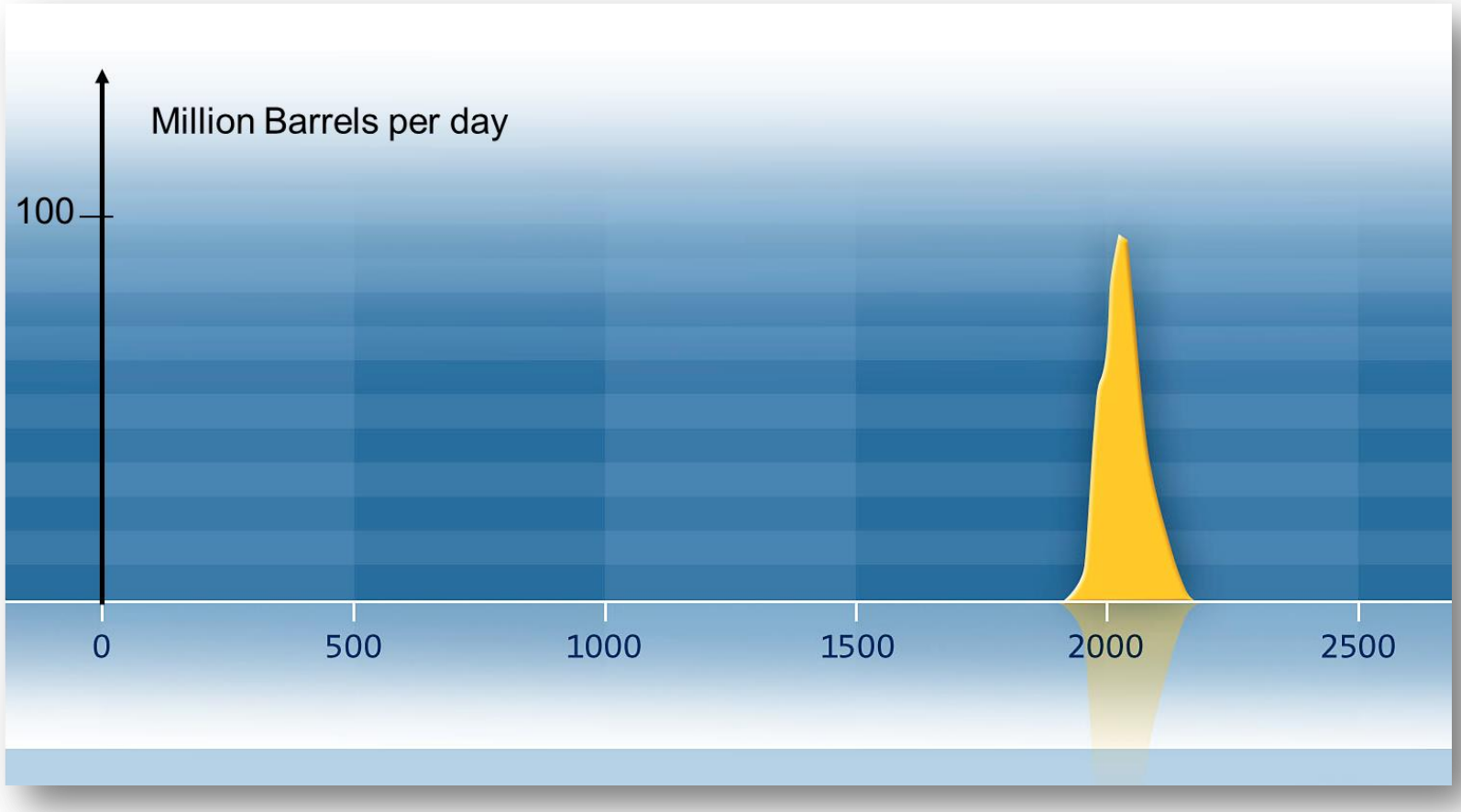
- The famous „candle in the night".



Source: GM, 2012

3 Energy Policy Targets and Potential Consequences

European Energy Policy Goals

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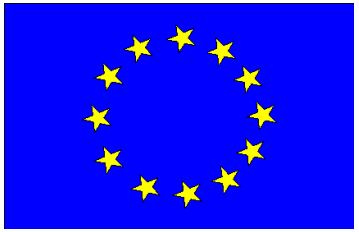
Energy Roadmap 2050 / Energy Security



- Decarbonise the energy system
- Increase share of renewable energy and improve energy efficiency
- Introduce low-carbon energy alternatives, i.e. to save on infrastructure costs
- Secure energy supply for EU in a common energy market, i.e. energy diversification

2020 / 2030 Targets

- Reduce energy consumption, @savings ≥20% / Increase energy efficiency by 30%
- Achieve greenhouse gas emissions reduction by 20% / 40% (based on 1990 levels)
- Increase share of renewable energies to ≥20% / ≥27% of consumption
- Achieve 10% renewable energy share in transport sector

Source: http://ec.europa.eu/energy/en/topics/energy-strategy

3 GHG Reduction Pathway until 2050, Germany

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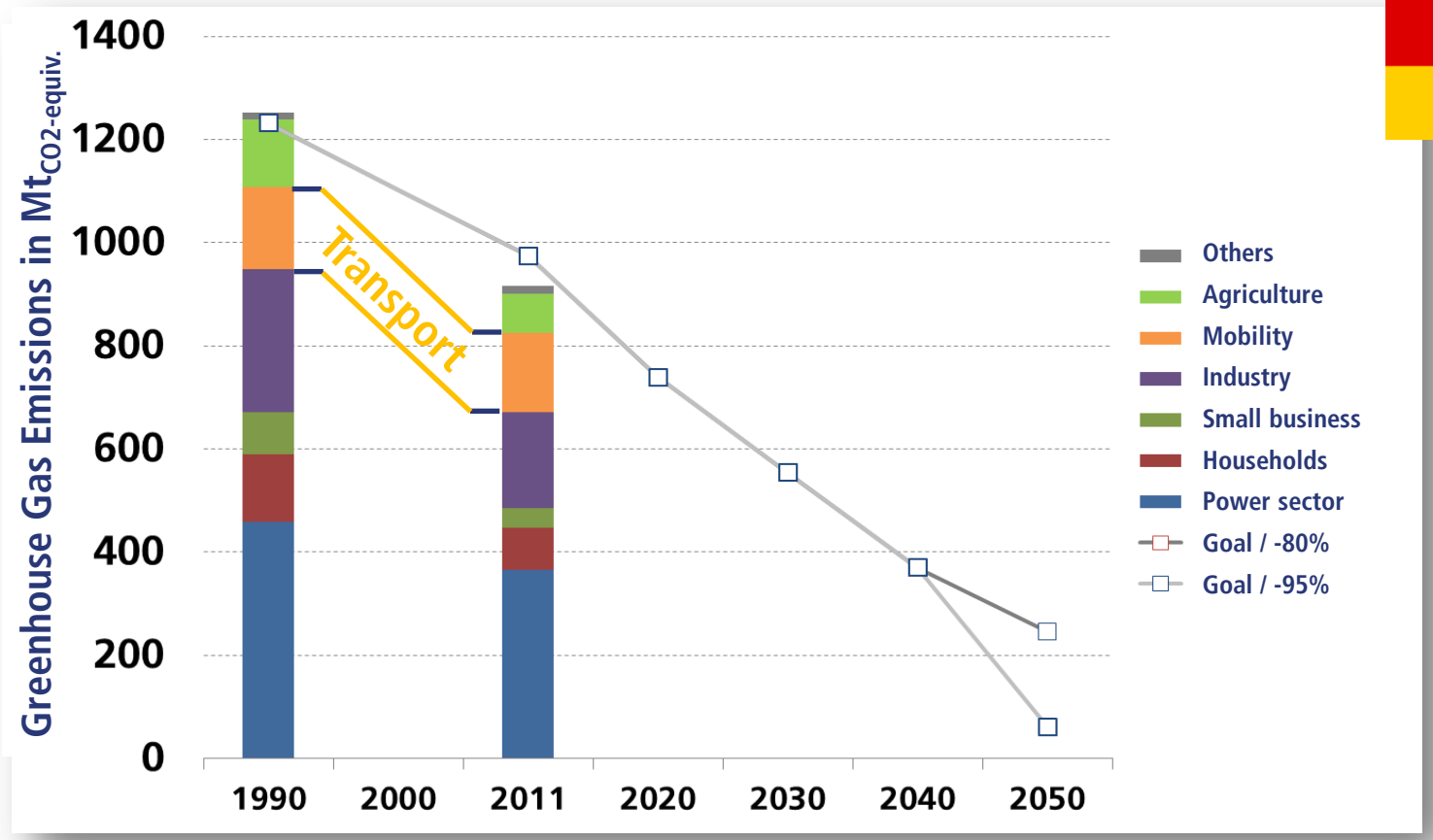
- The transport sector has not contributed to GHG emission reduction.
- What transport does not contribute, other sectors have to compensate for.



Source: FhG-ISE, 2015

3 German Energy Policy Goals

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Phase-out all nuclear electricity by 2022

Renewable electricity share (today: 25.5%)

2020	2025	2030	2035	2040	2050
≥35%	→40-45%	→50%	→55-60%	→~65%	→≥80%

Electricity end-use (base year 2008)

- -10% by 2020
- -25% by 2025

GHG emission reduction (base year 1990)

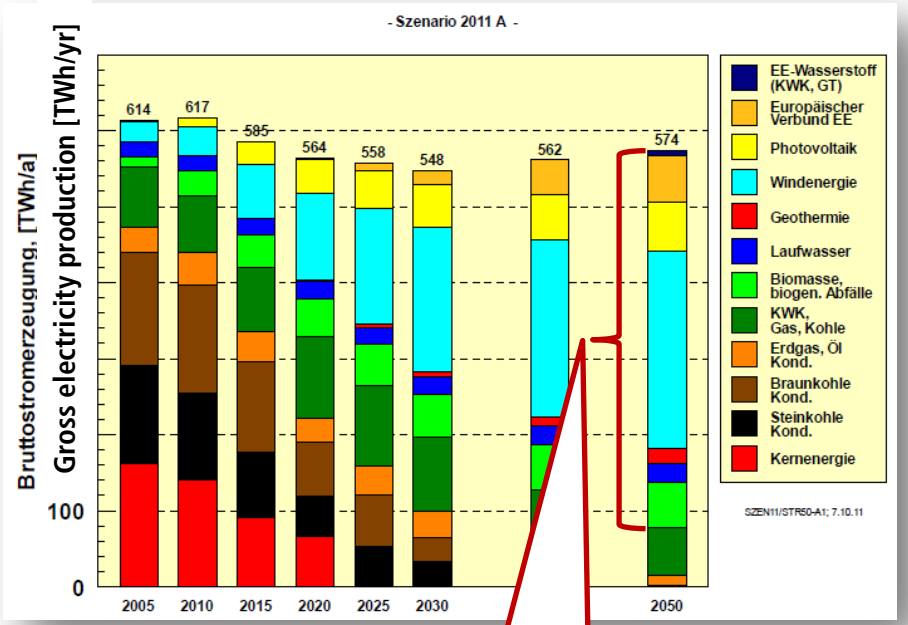
- at least -40% by 2020
- -80 to -95% by 2050

Primary energy use (base year 2008)

- -20% by 2020
- -50% by 2050

Source: Leitstudie, 2012

Electricity generation portfolio Germany 2005 – 2050 (EEG – Federal REN Energy Law)



Renewable Energy Law, 2015
Energy concept German Federal Government (September 2010)

4 Realities

4 Fossil Resources We Cannot Burn Before 2050

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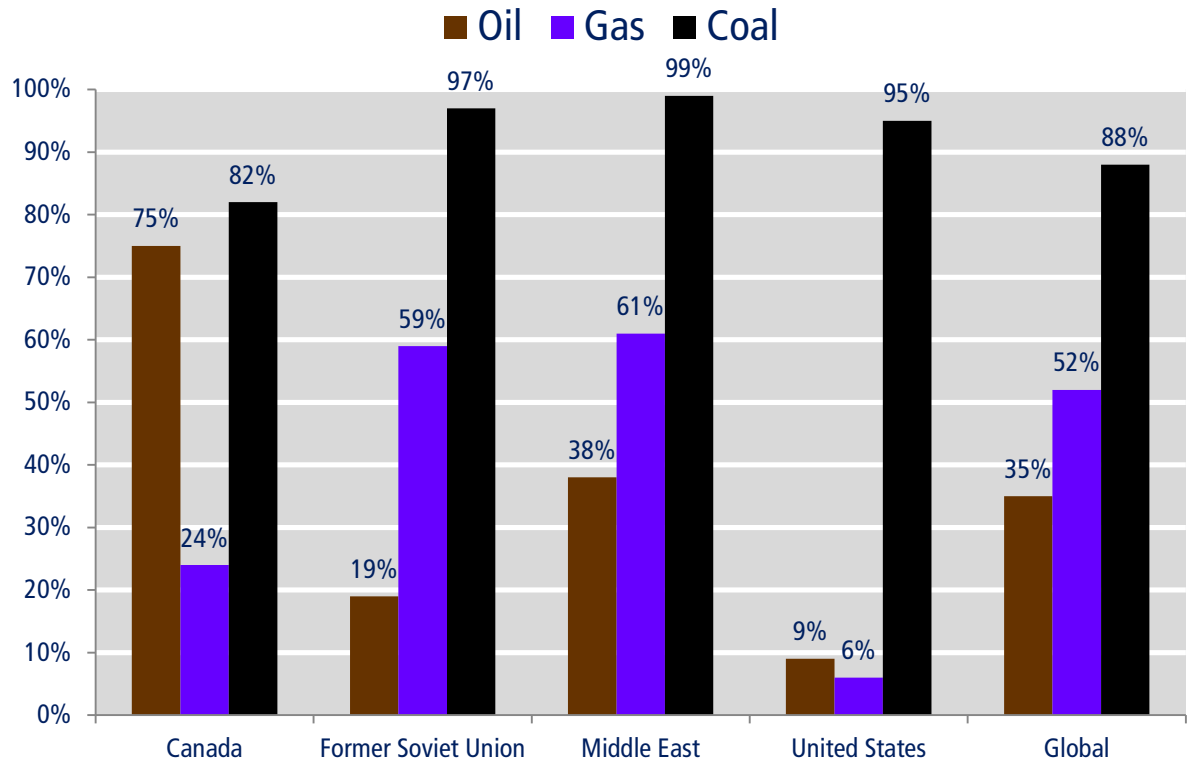
- Experts predict that to keep global warming down, much of our current reserves of fossil fuels must be left in the ground.
- Below see regional breakdowns of urburnable oil, gas and coal reserves.



Source: LBST, based on McGlade, Ekins, 2014

4 Electricity Production from Wind & PV, January 2015

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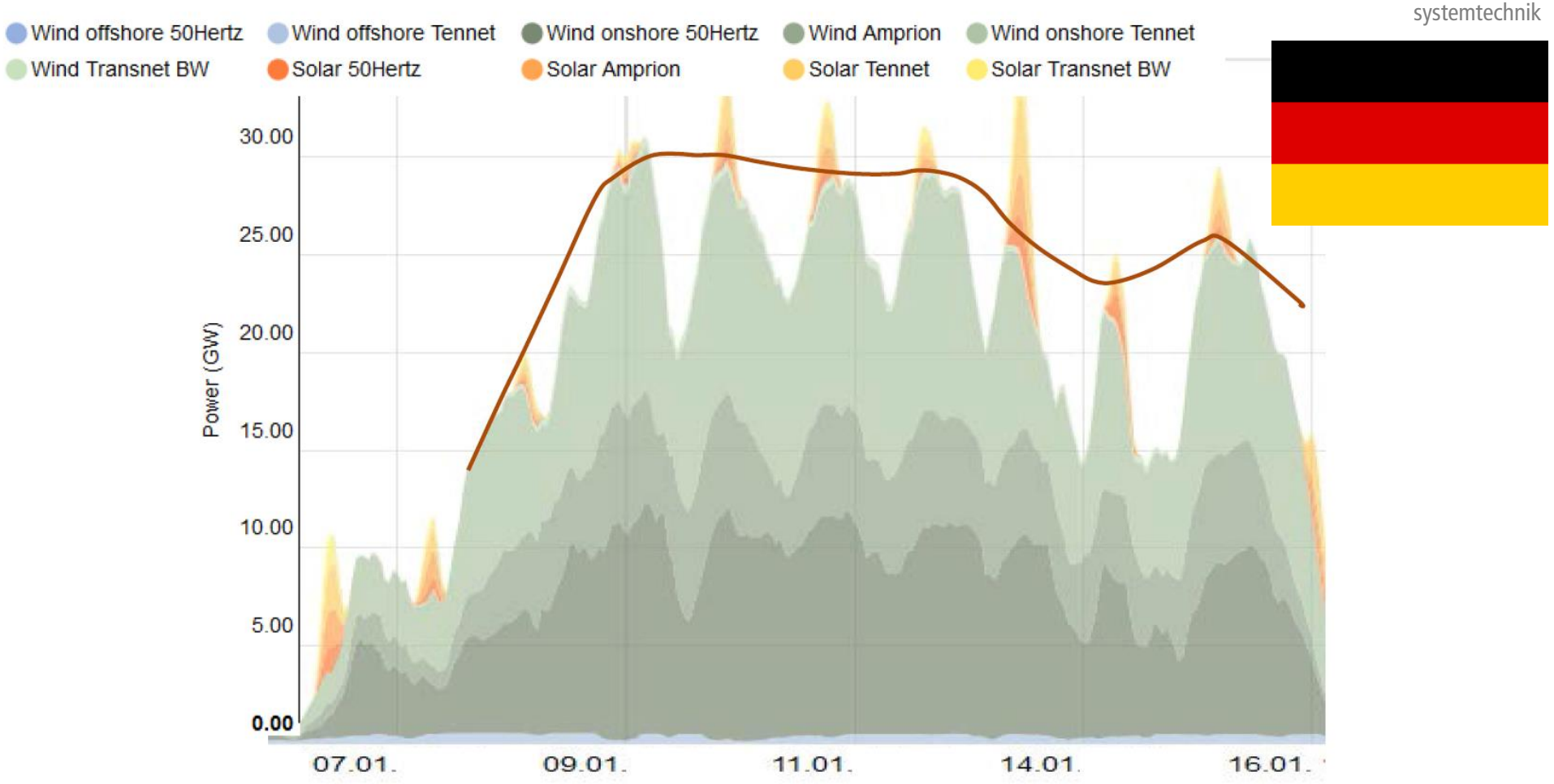

Source: www.energy-charts.de

Mar-24

4 Global CO_2 emissions Germany [$Mt_{CO2\text{-}eqiv.}$]

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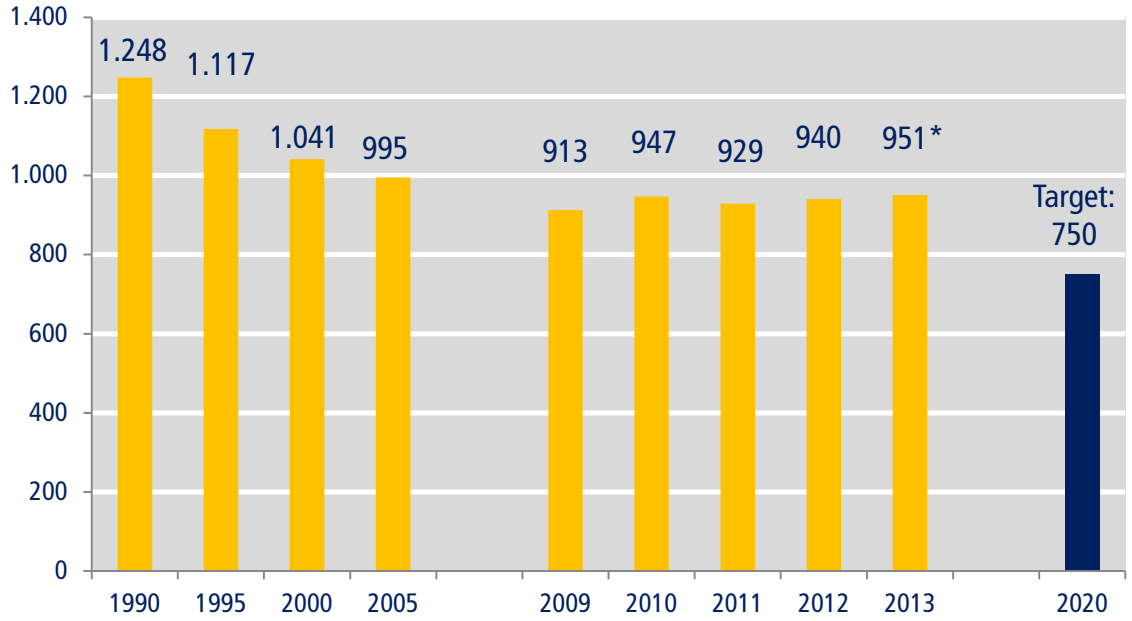
- CO_2-emissions have increased even though REN electricity share of gross power production has risen from 22% (2012) to 24% (2013).
- Reason is increased coal based electricity production and increase of power exports, coal based electricity prices piggybacking on low marginal REN electricity price in surplus periods.



* Near term prognosis

Source: LBST, based on Tagesschau, 2014; BMU, 2014

4 US Auto Sales by Segment 2014 Versus 2008

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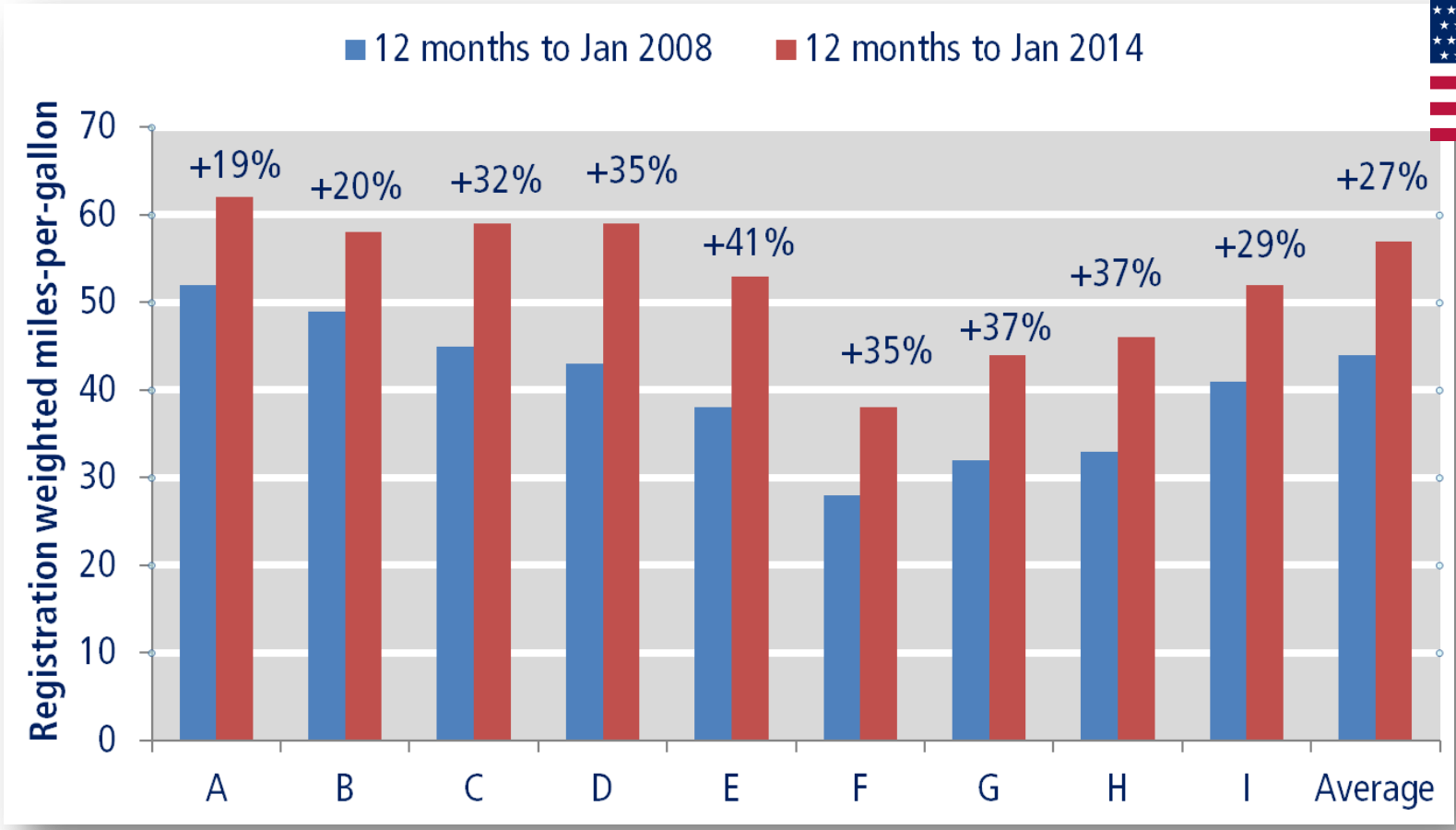
- Growth specifically in large car segments.



A – Mini
B – Supermini
C – Lower Medium
D – Upper Medium
E – Executive
F – Luxury
G – Specialist Sports
H – Dual Purpose
I – Multi-Purpose Vehicle

Source: LBST, based on „This is Money.co.uk", Feb 2014

4 Electricity Demand for Mobility (2050) [TWh/a]

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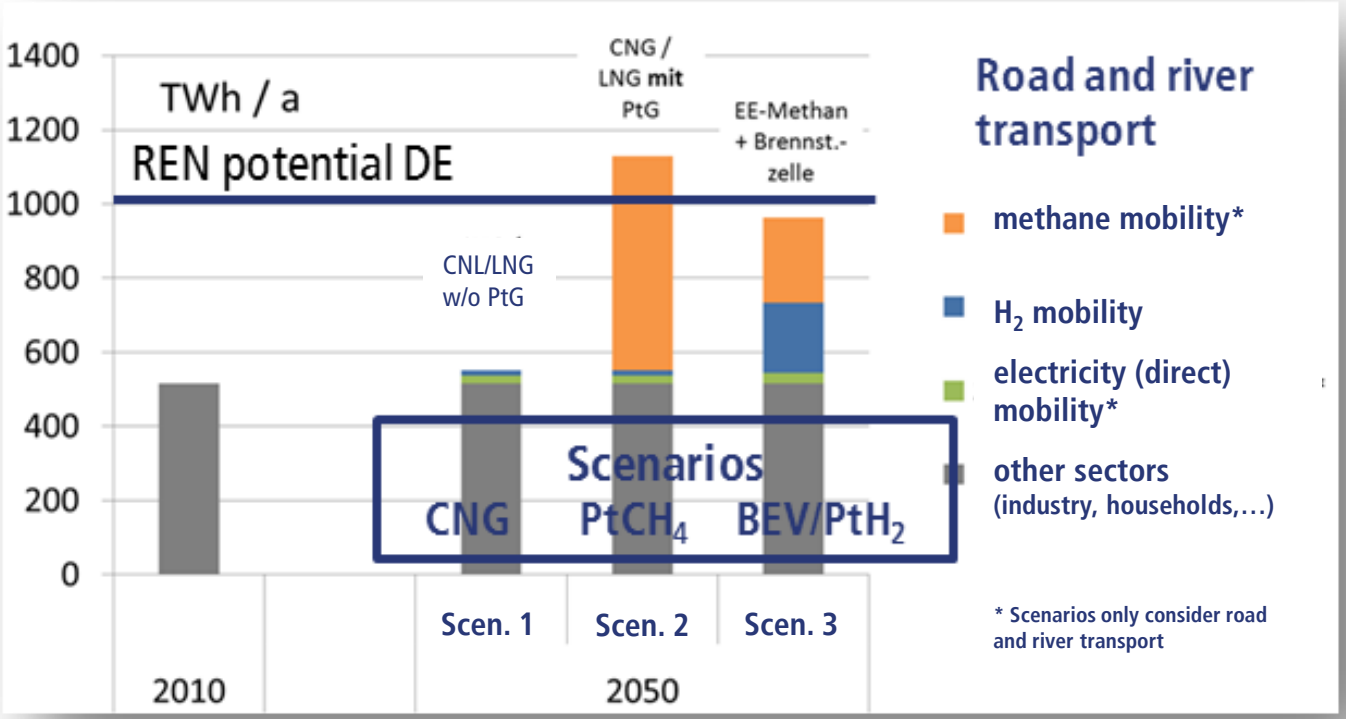
- Doubling of electricity consumption for transport.



Source: MKS-PtG, LBST 2014

4 Resource Intensity of New Energy World

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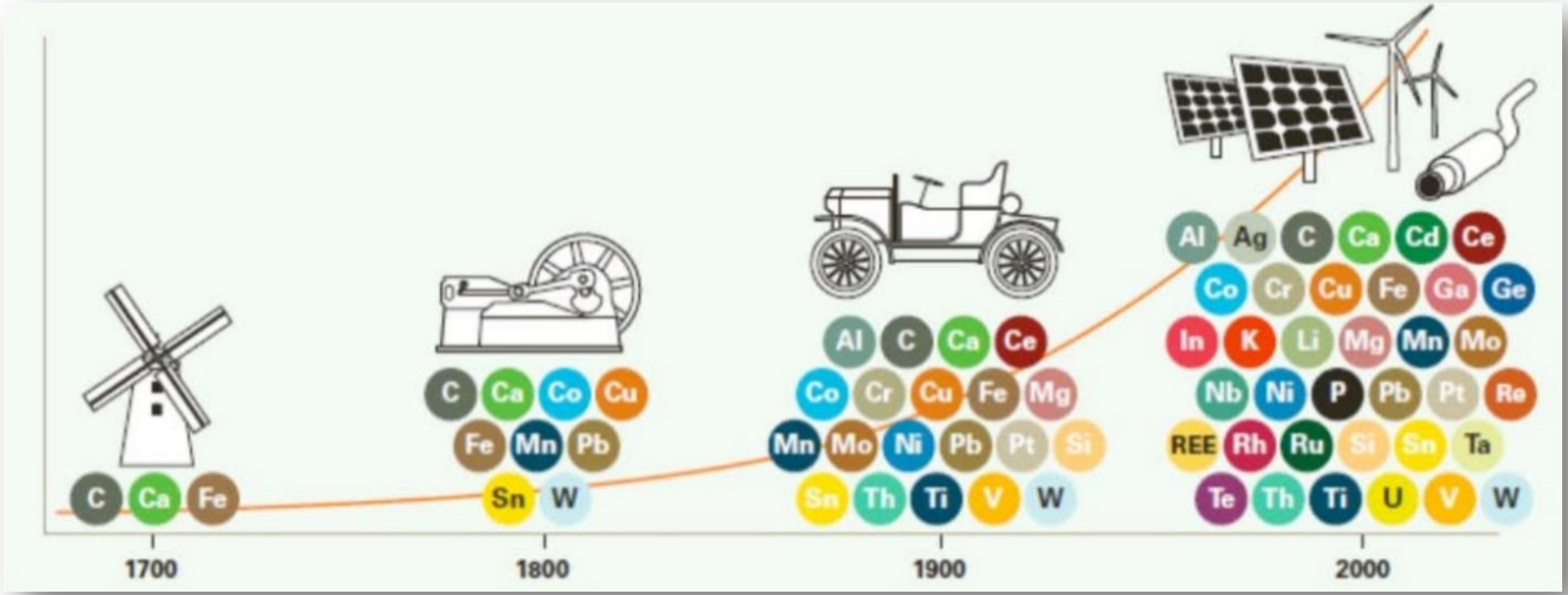
- Efficient energy technologies come at a cost.



Source: Urban Mining, Reller, Uni Augsburg, 2012

4 Using Rare Earths in Automobile Production

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Glass + Mirror polish:
Cer

25 small E-motors:
Nd-magnets

Touch Screen:
Indiumoxide
Luthetium

Catalysts: Cer, Lanthan, Zirkonium

Alloys in NiMH-batteries: Cer, Lanthan

Hybrid drive:
Neodymium
Praseodymium
Dysprosium
Terbium

Source: LBST, 2014, based on Reller, 2009

5 Global Implementation Strategies and Consequences for Norway

5 Global World Energy Supply from Renewables

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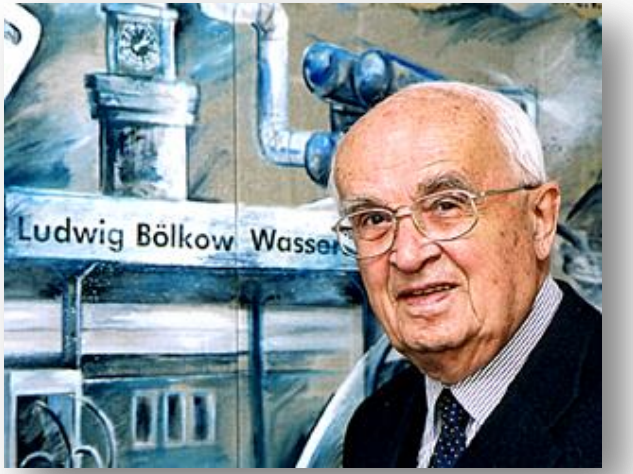
- World's energy demand could principally be fully supplied by a small area of PV plants in the Sahara desert.



Dr. Ludwig Bölkow, † 2003

World

Europe

Germany

Source: Ludwig Bölkow: Obliged to the future – Memoirs, 2000

5 World's Energy Future Dominated by REN Electricity

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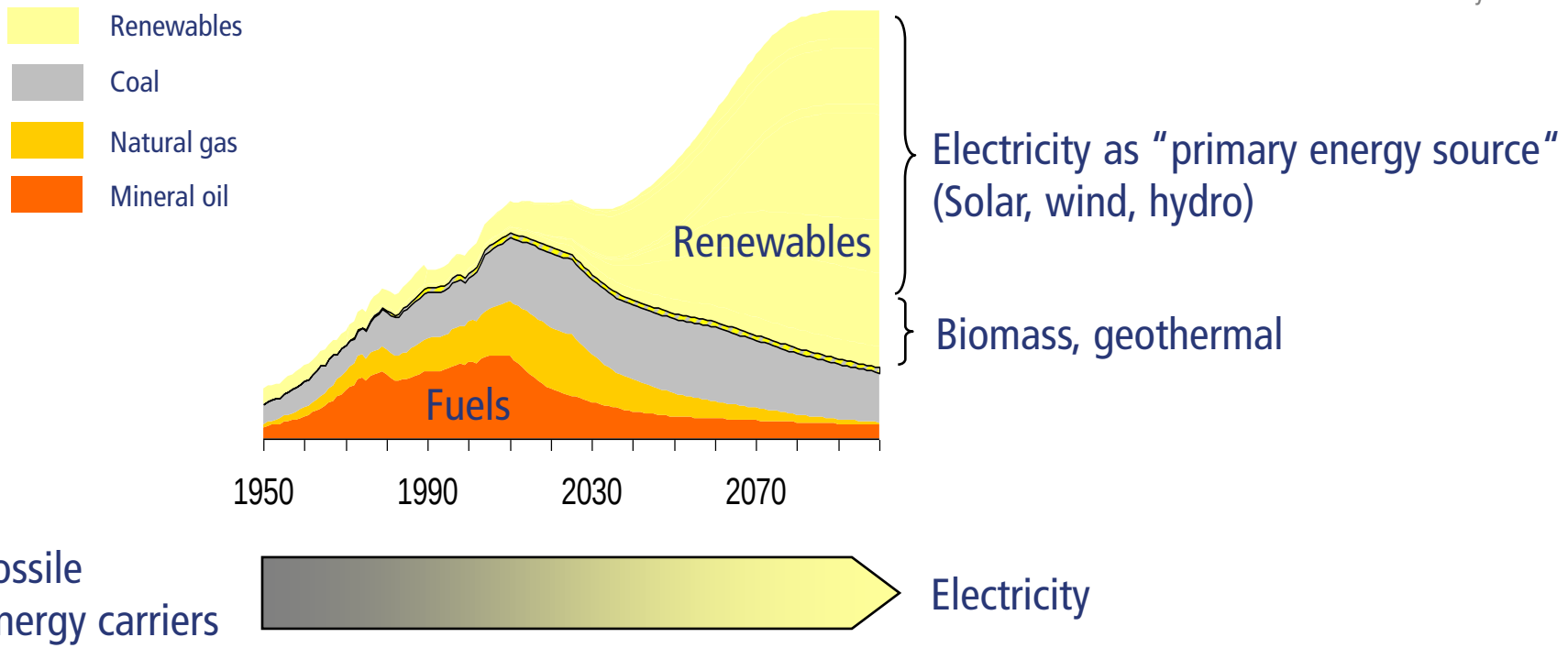

Renewable electricity has different properties than fossil energy carriers:

- Challenges for storage
- Inelastic coupling of end-use and production

Source: LBST, 2014, AWEO, 2006

5 Coupling of Energy Sectors by Hydrogen

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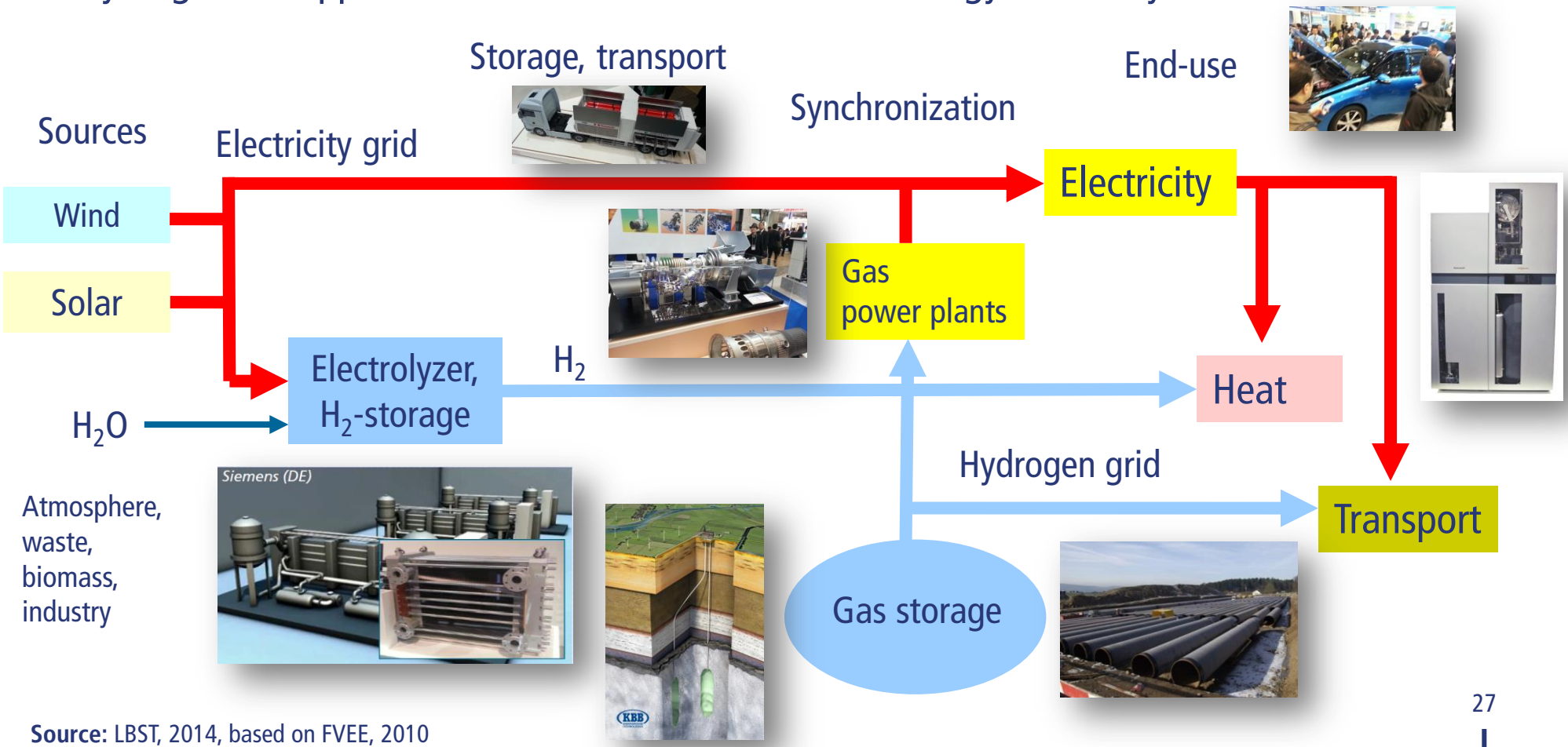
- Instead of the phrase "Hydrogen Society" it is more appropriate to consider "hydrogen to support the introduction of renewable energy/electricity".



Source: LBST, 2014, based on FVEE, 2010
Photos: LBST, KHI, KBB, FhG-ISE, Siemens, Toyota, Viessmann/Panasonic
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5 Global World Energy Supply from Renewables

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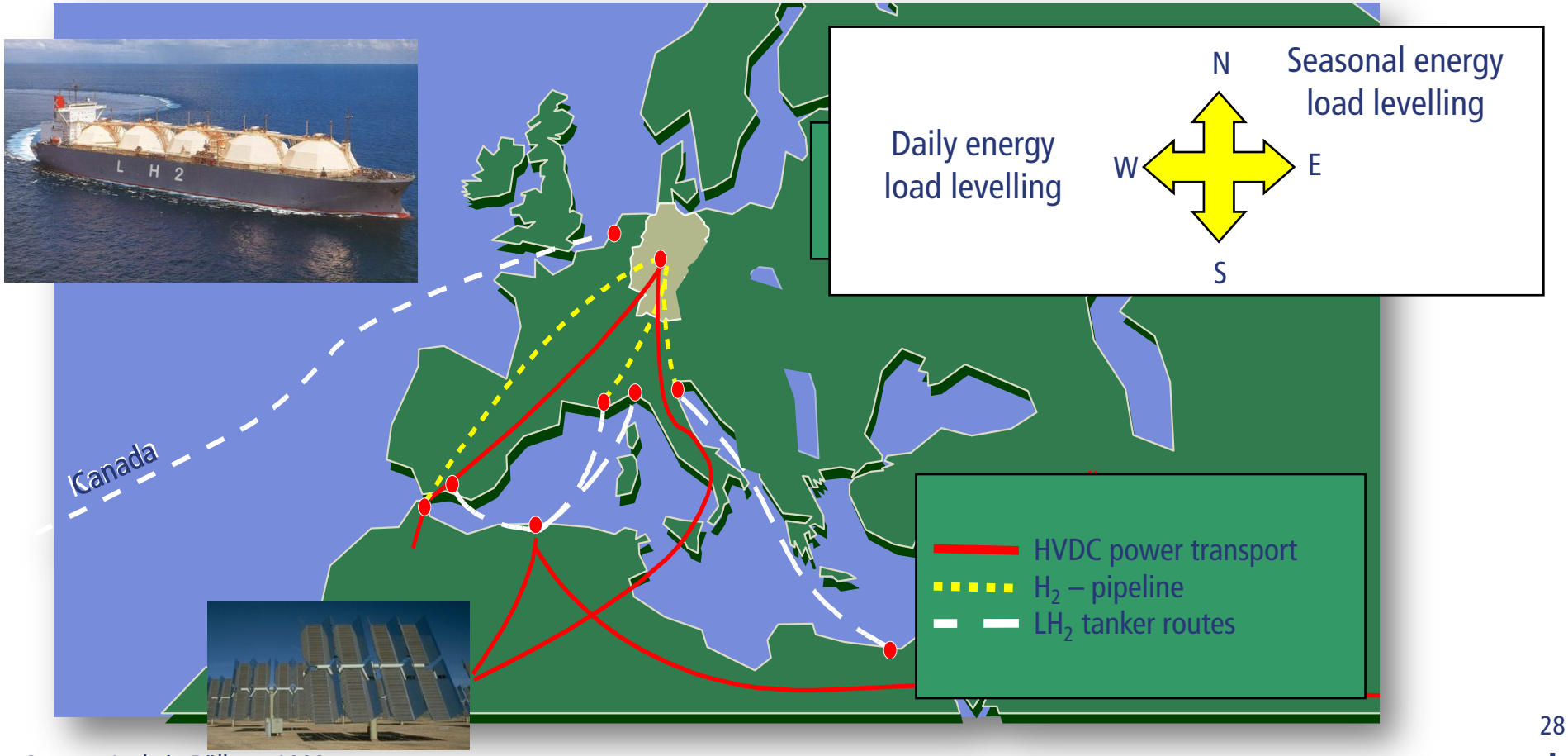
- Vision of a seasonal and daily distribution of renewable energy and import to the industrial world (here: Germany).



Source: Ludwig Bölkow, 1988

5 Euro-Quebec Hydro-Hydrogen Pilot Project (EQHHPP)

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Source: LBST, 1989-2000

5 World Energy Net (WE-NET) Japan

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- WE-NET – Vision of a hydrogen based full energy system.

Source: WE-NET, 1995

5 Hydrogen Corridor Projects Worldwide

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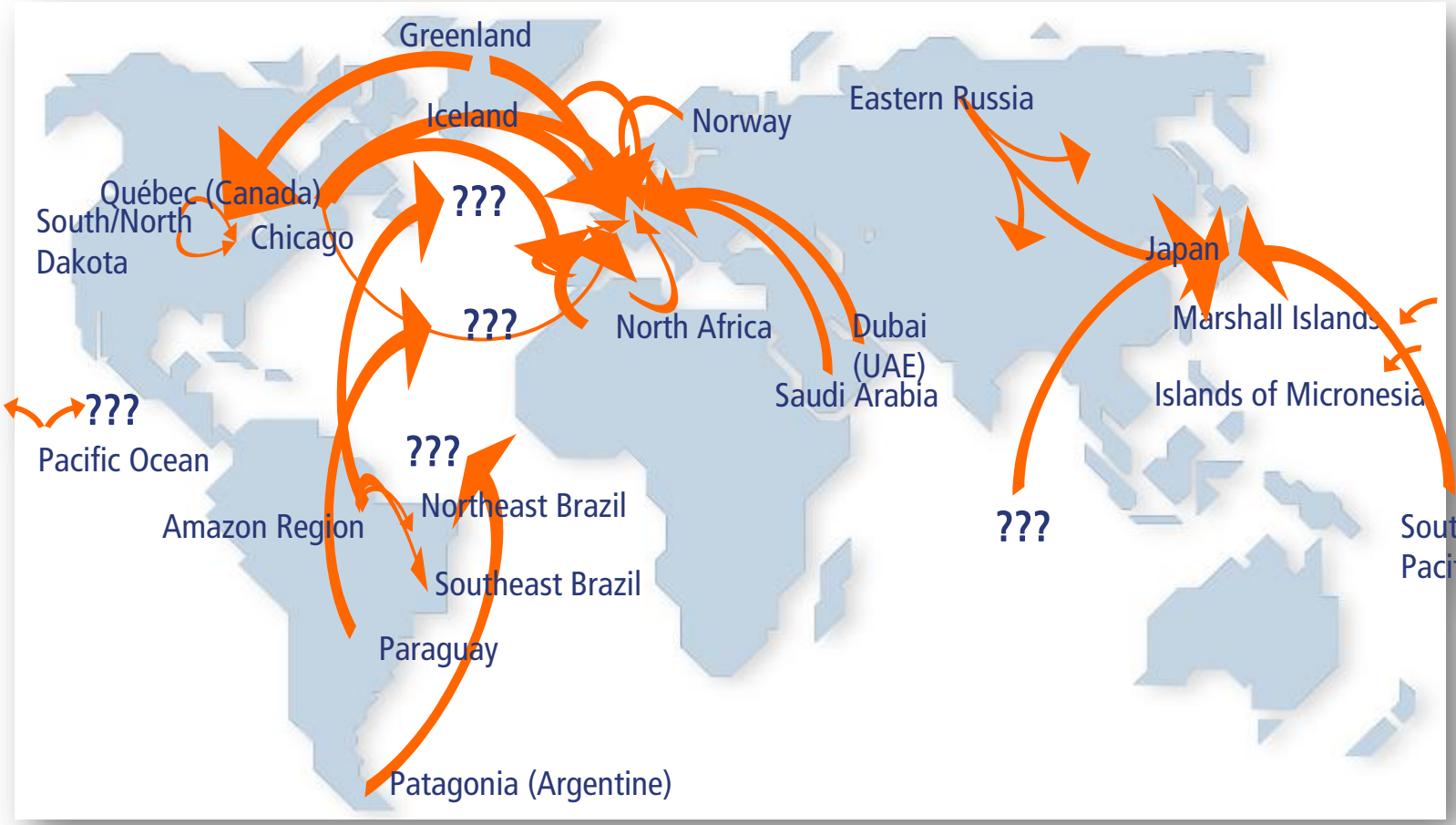
- Already by 2005 hydrogen energy vectors around the World had been analysed.



Source: LBST for ENCOURAGED - EU-project, chapter on H_2-corridors, 2005

5 Norwegian Hydro Energy in Germany Project (NHEG)

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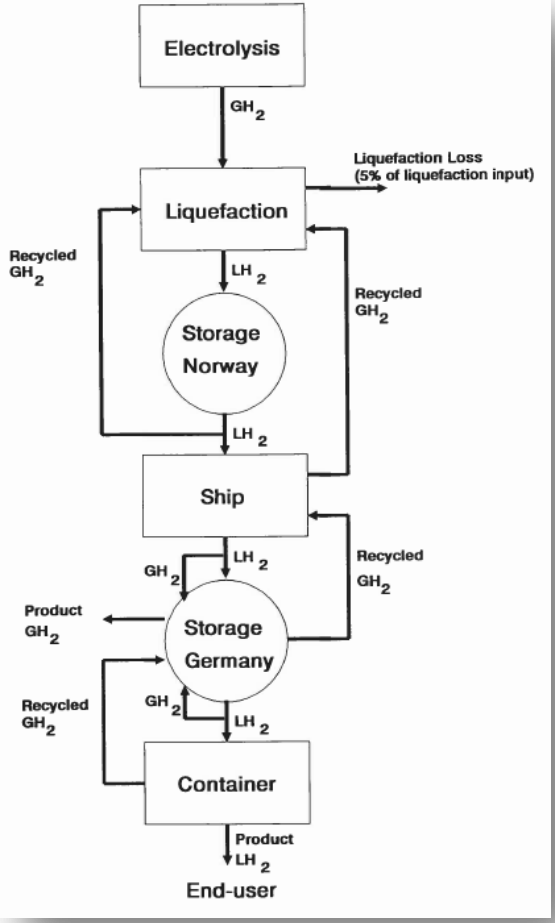

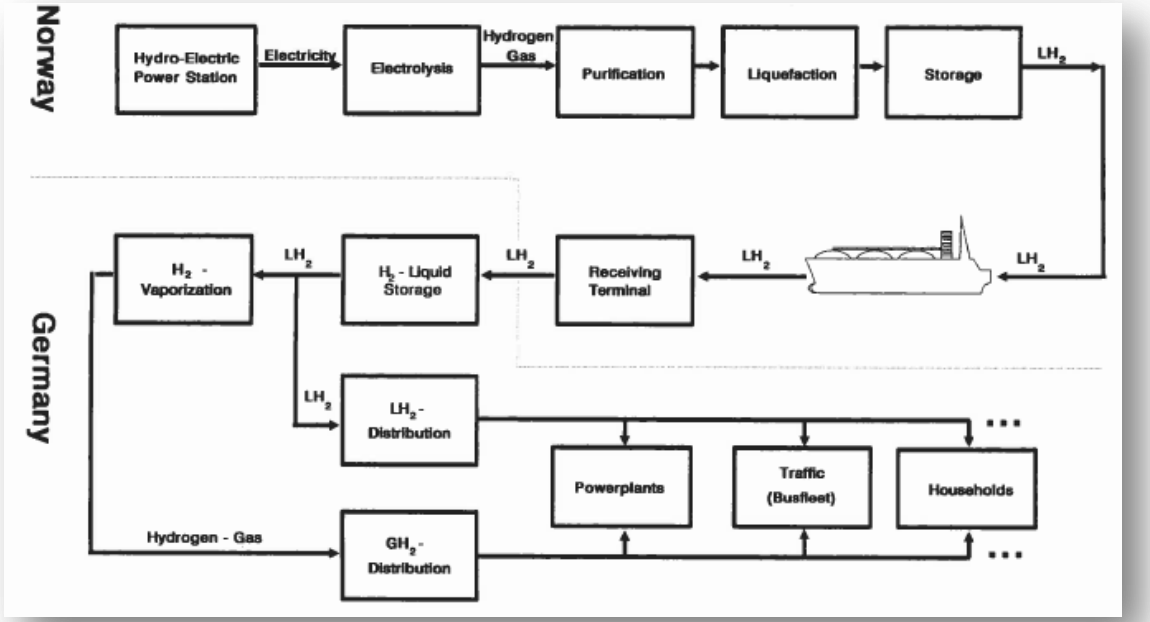

Source: LBST, Norsk Hydro, and others, 1992

5 Norwegian Hydrogen Motorway Grid (HyNOR)

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Th!nk (700 bar, range extender FC)

Quantum Toyota H2 hybrid

1st fuelling station at Grenland

Source: HyNOR, 2007

Mar-24

5 Analysis of Energy Export from Norway (NorWays)

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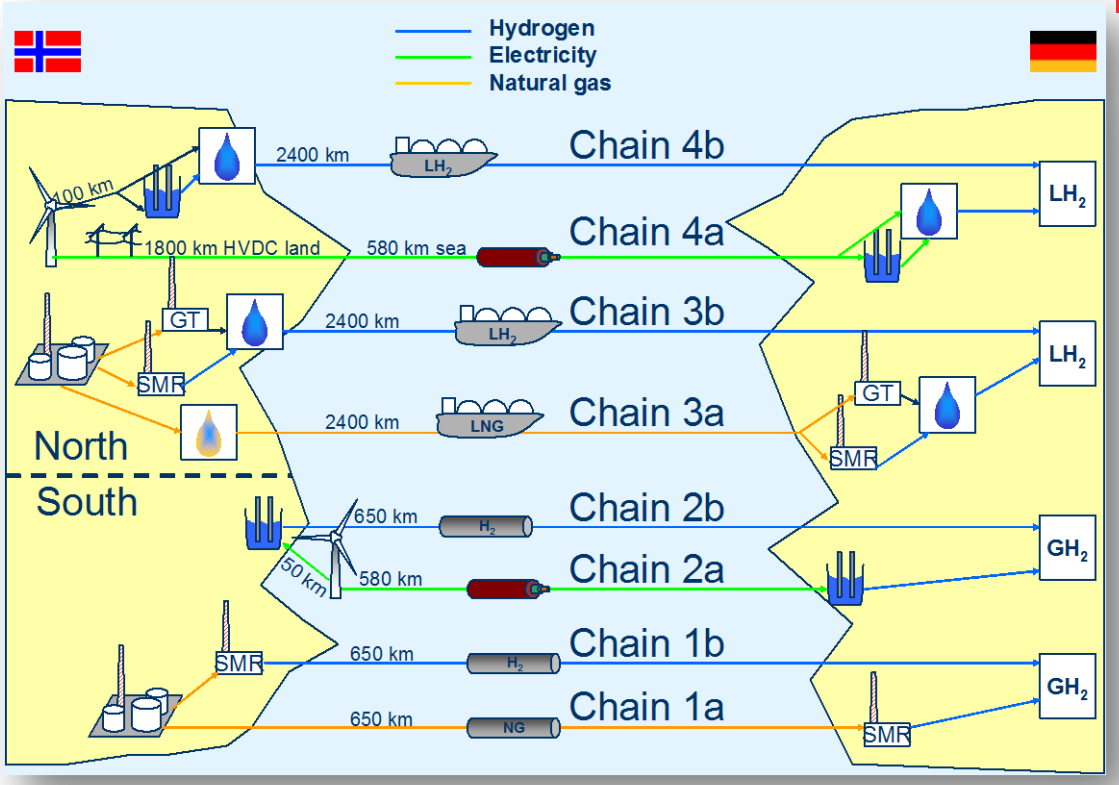
- Export of hydrogen from NG seems inferior to direct NG export (given the feasibility of CO_2 storage at the destination).
- Export of hydrogen from renewable energy from Norway to central Europe seems advantageous against HVDC in the future!



Source: NorWays project, 2008

5 Norway has Reached Peak Oil Around the Year 2001

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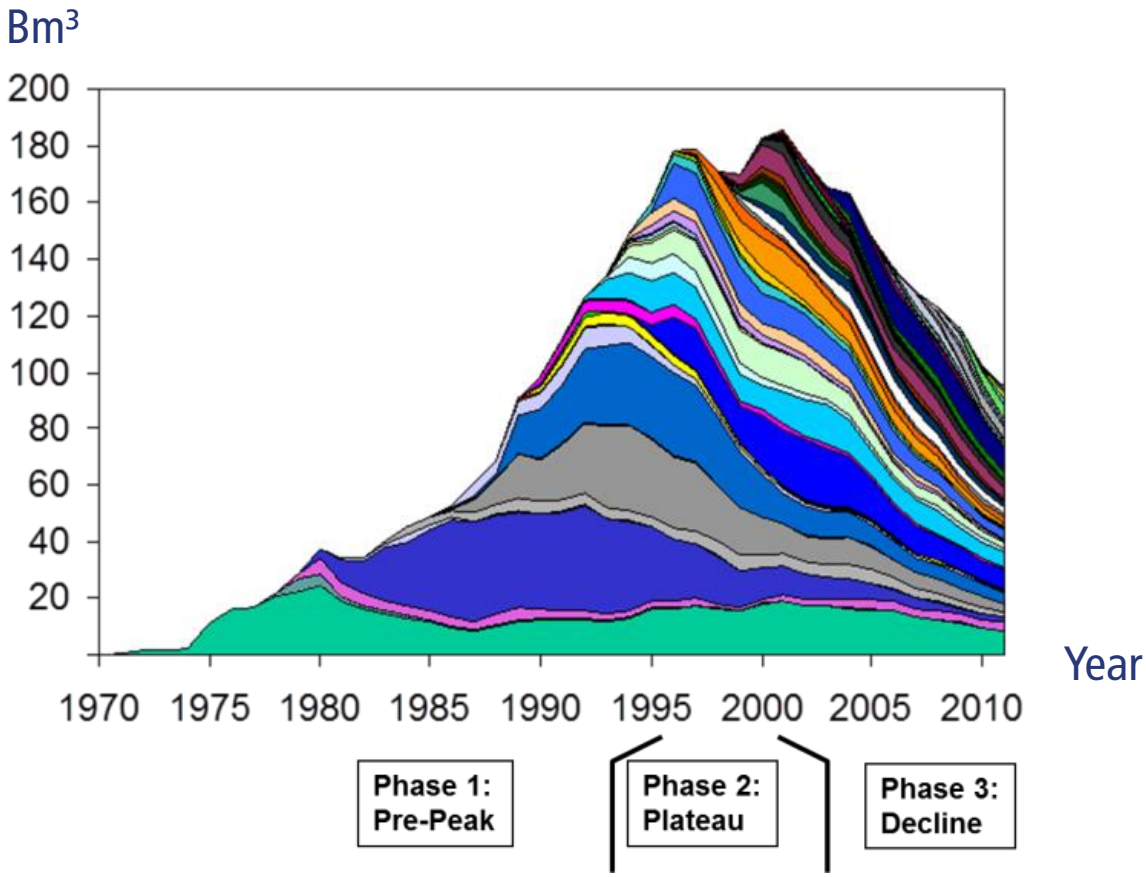
- For Norwegian industry energy exports play a pivotal role
- What comes after peak oil and peak gas?



Source: LBST analysis based on NPD, 2012

5 Potential for Norwegian Renewable Electricity

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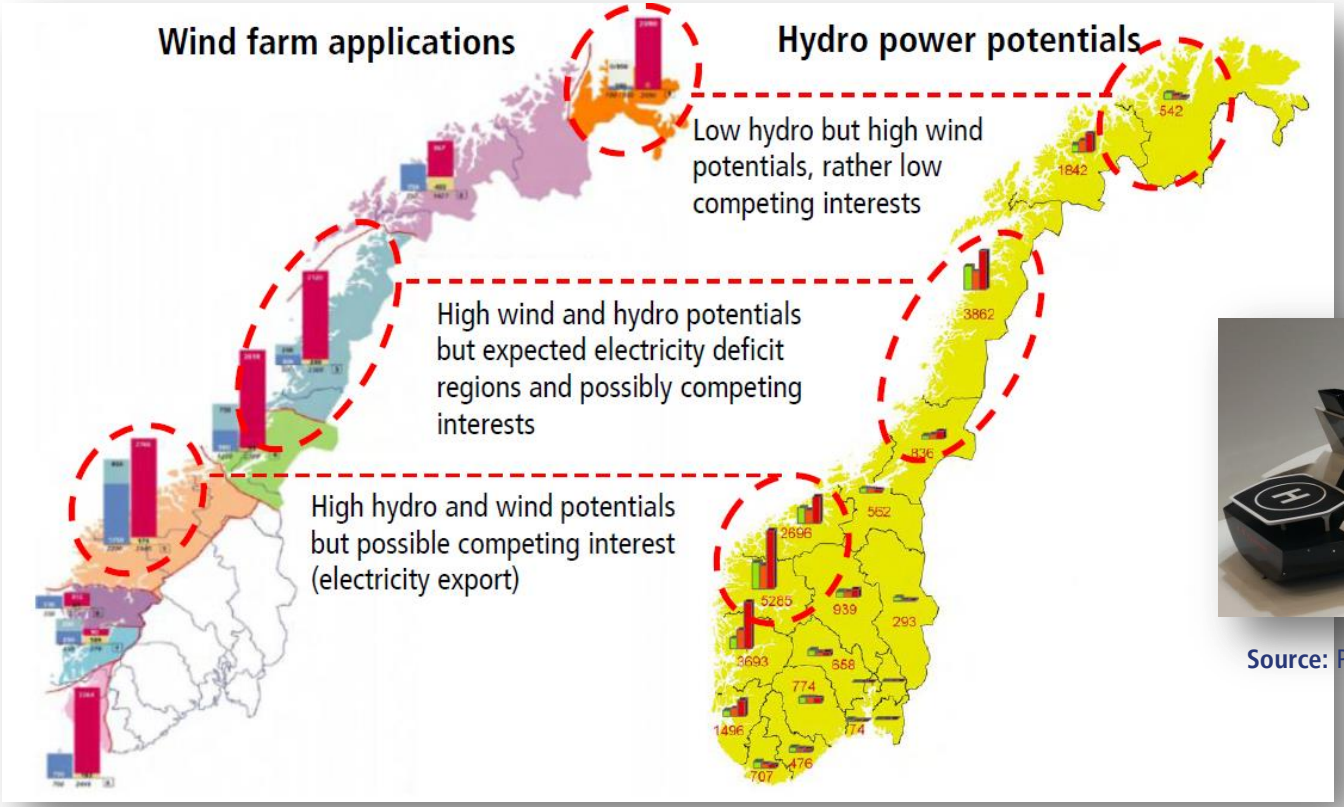
- In principle, the potential for hydrogen from renewable electricity in Norway is:
- 15 TWh_{el} (H_2 from grid), 7 TWh_{el} (H_2 from dedicated windfarms) and 15 TWh_{el} (H_2 from dedicated small hydro), parts of which could be exported, e.g. to Japan



Source: LBST/SINTEF study for Technova/AIST, 2014

Source: Photo by LBST of KHI LH_2 ship, 2015

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