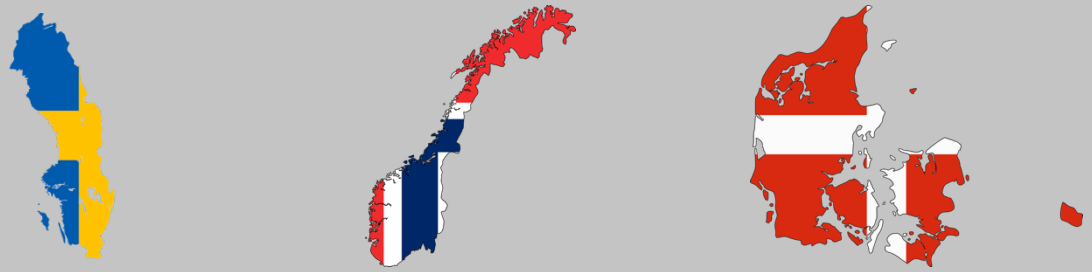
Alternative Fuels in the Nordic Region (Sweden, Norway, Denmark)



Bryan Faeth
Haitham Al-Abdali
Alan Arvelo

Oil: World's Primary Transportation Fuel

All nations use oil to power their transportation fleets.

Major oil reserves are concentrated in very few countries.

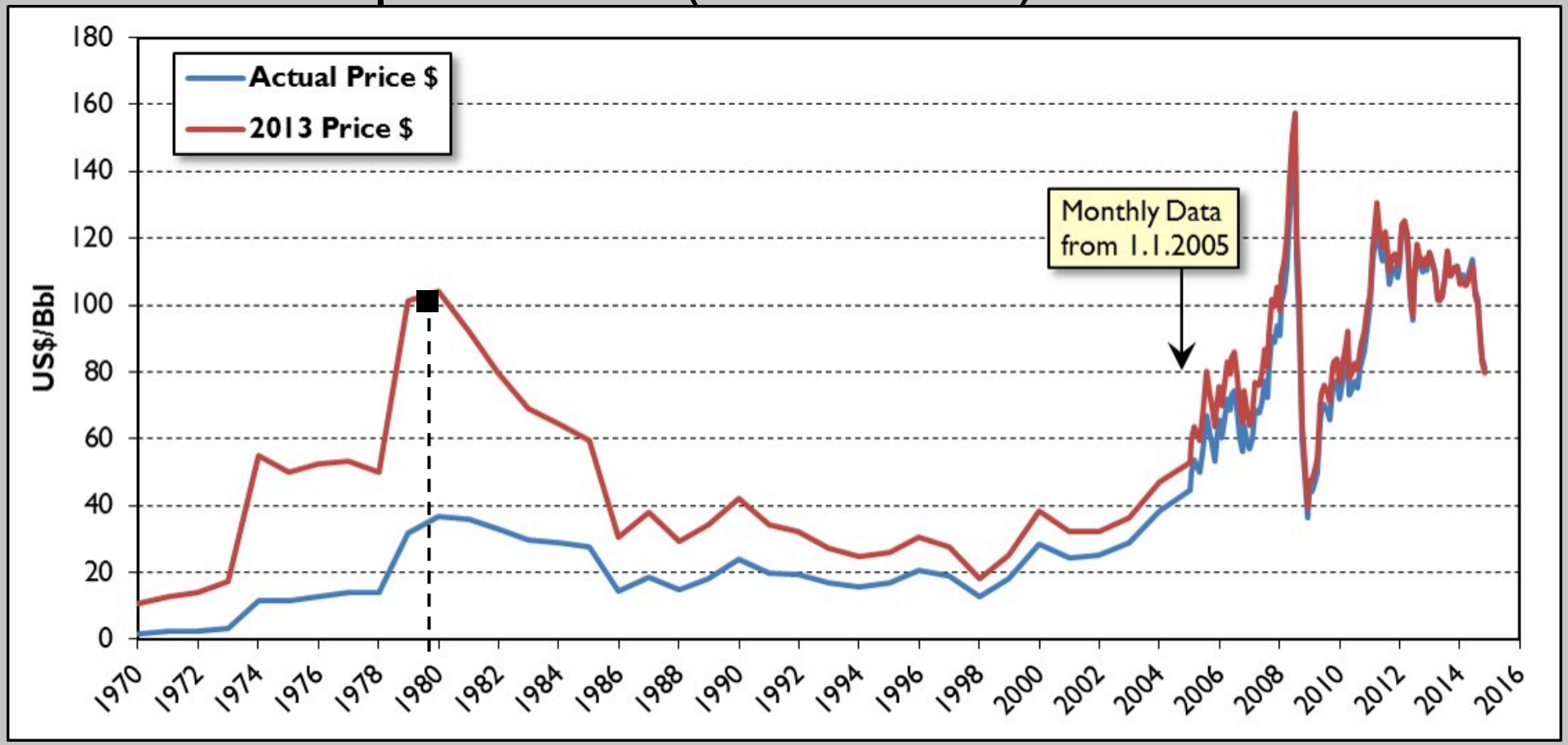
Oil reserves are quickly diminishing, resources are limited.

The quality of extractable crudes is diminishing.

More intensive processing will increase retail prices.

Source: International Energy Agency. Energy Outlook/Oil Prices. 2013.

Oil Prices per Barrel (1970-2015)



Source: BP “Statistical Review of World Energy, 2014, Notebook”

Eradicating Oil Dependence

- The impact of oil prices on Nordic nations' economic growth and employment
- The great potential to use Nordic nations' own clean renewable energy resources in place of oil
- The threat of climate change resulting from the extensive burning of fossil fuels
- The link between oil, peace, and security throughout the world

Source: International Energy Agency. Energy Outlook/Oil Prices. 2013.

Objective:

Determine which alternative transportation fuels the Nordic Region can & shall adopt to achieve an oil-independent fleet (ground) by 2050

Hypothesis:

Through the utilization of:

1) Electricity

3) Natural Gas (CNG, LNG)

4) Biofuels (Ethanol, Biodiesel)

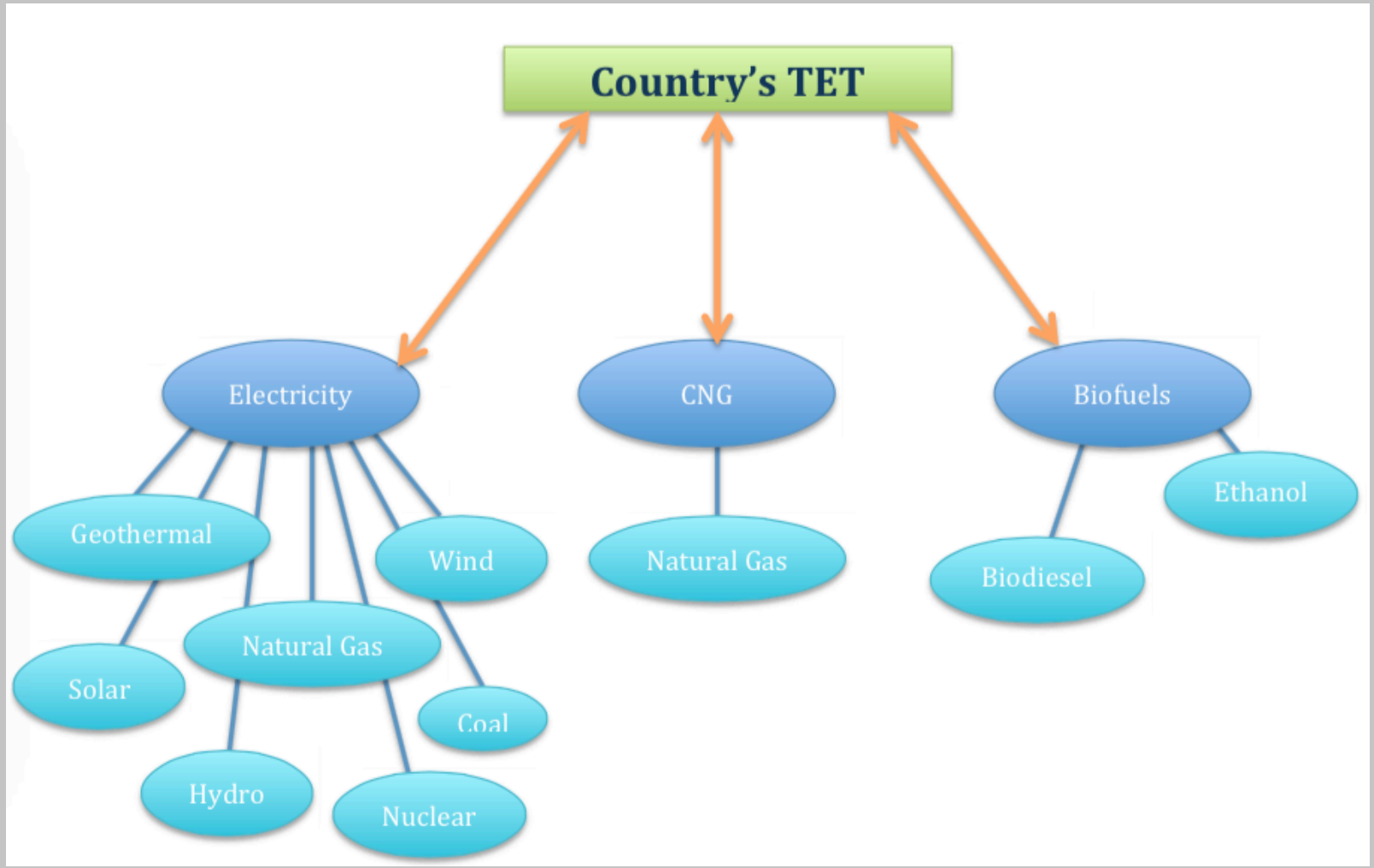
Nordic countries can develop an oil-independent ground transportation fleet by 2050.

1)Calculated Values for TET50

Expected Energy needed for Ground Transportation

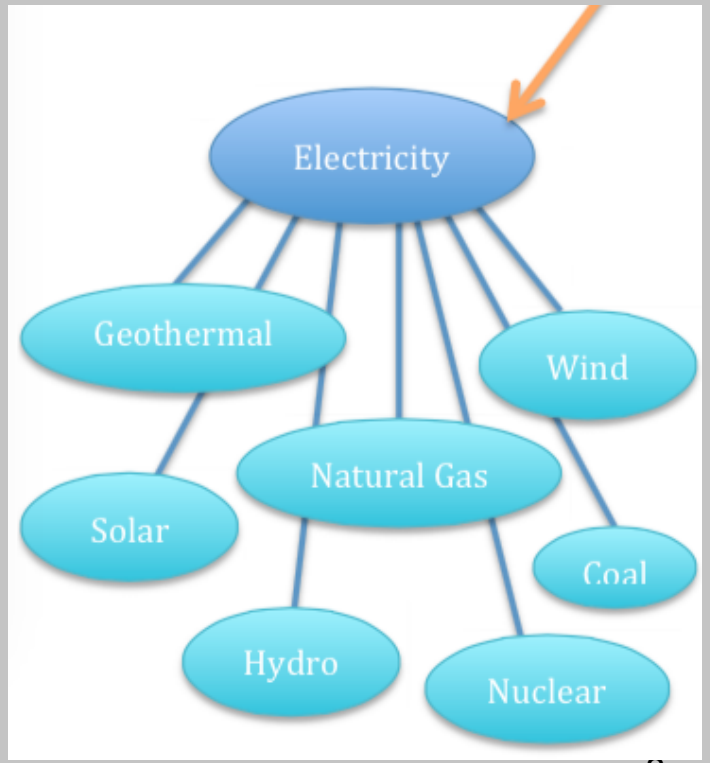
	ktoe	GWh	TJ
Norway	**4,603**	**53,533**	**192,718**
Denmark	**4,019**	**46,741**	**168,267**
Sweden	**7,545**	**87,748**	**315,894**

Source: International Energy Agency. Transportation Energy by Country. Statistics. 2013.

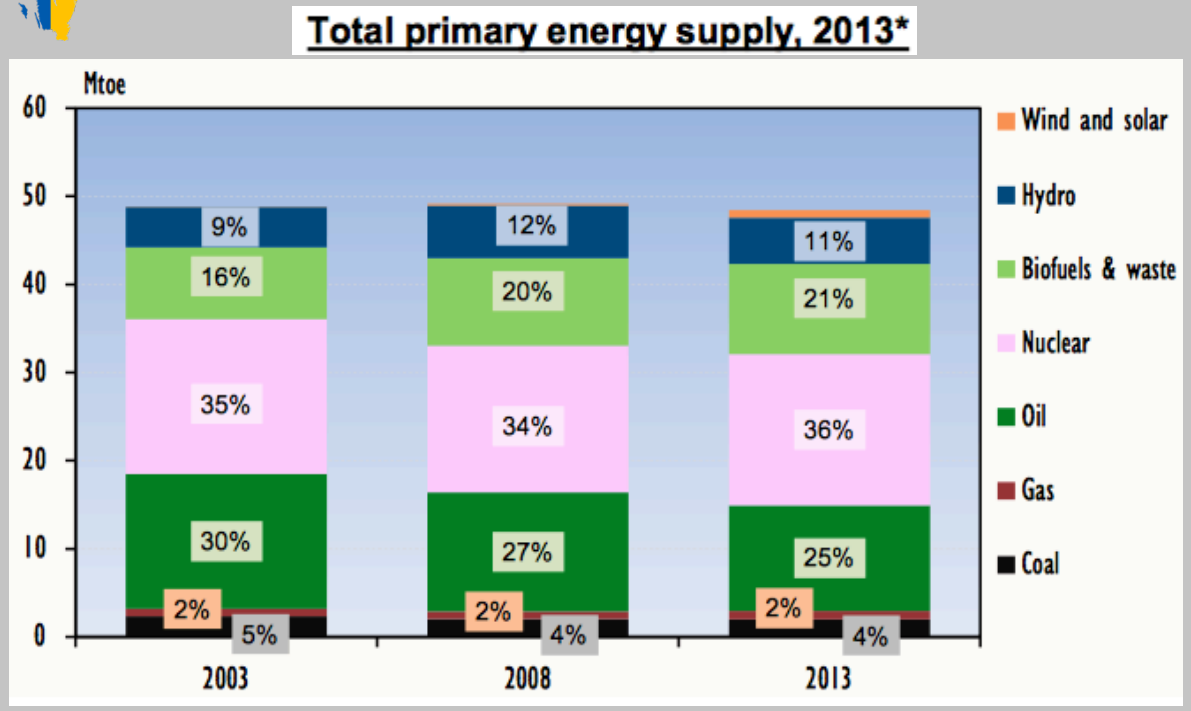

Country's TET
Electricity
CNG
Biofuels
Geothermal
Wind
Natural Gas
Solar
Natural Gas
Coal
Hydro
Nuclear
Natural Gas
Biodiesel
Ethanol

2) Estimate Conversion of Primary Energy Sources to Electricity

For Sweden, Denmark, and Norway.



Sweden



Sweden-Overview. International Energy Agency. 2013

Oil-products are mainly used for transportation in Sweden.

Oil is the primary source of transportation energy in Sweden (and the world).

Sweden: Energy Used for Transportation

We intend to calculate which energy source can substitute oil as primary transportation fuel.

(ktoe)	Coal*	Crude oil*	Oil products	Natural gas	Nuclear	Hydro	Geothermal, solar, etc.	Biofuels and waste	Electricity	Heat	Total**
Transport	**0**	**0**	**6650**	**53**	**0**	**0**	**0**	**611**	**231**	**0**	**7545**

Sweden Eergy Balances. International Energy Agency. 2012

Oil products provide 88% of the total transportation energy (TET).

To eliminate oil products, the contributions of Electricity, NG, and Biofuels need to provide this 88% = 6650 ktoe = 77.3 TWh.

Sweden: Projected Transportation Energy (2050)

Population (2015) = 9.8 million

Population (2050) = 11.3 million

Expected Total Energy for Transportation in 2050 (TET50) = 103.7 TWh

"Residential energy consumption will grow at a slower rate of 9.1% to 2030, while transport usage will remain relatively constant, growing by a mere 0.5% over the nineteen years."

Sweden: Electricity

The extra 103.7 TWh is over a fleet of IC engine vehicles.

For an EV fleet the energy needed will be smaller.

Efficiency of an IC engine = 25% Efficiency of an electric motor = 90%

Physics Portal, Ohio State University

Energy needed to power the EV fleet = <u>34.6 TWh</u>

This will be attempted by Nuclear, Hydro, and Wind deployment, as these are Sweden's energy sources with the potential to achieve the project's goal via electricity.

Sweden: Nuclear

Current: 4 sites.

Total installed capacity: 10 GW

Average 1 GW/reactor

Boiling water reactors is the most common technology.

Capacity Addition required: 4 GW

New reactors needed: 4

Sweden: Hydro

- Most plants built between 1940 - 1980.
- Most plants in Lube River.
- Unharnessed rivers protected by law, or insufficient water flow.

+1200 plants, most small-scale.

6 Hydro plants ≥ 400 MW

18 Hydro plants ≥ 200 MW

46 Hydro plants ≥ 100 MW

26 Hydro plants of an average 152 MW are required

Sweden: Wind

Currently, 5 wind farms: 100 MW average capacity

39 Onshore Wind Farms of 100 MW are required.

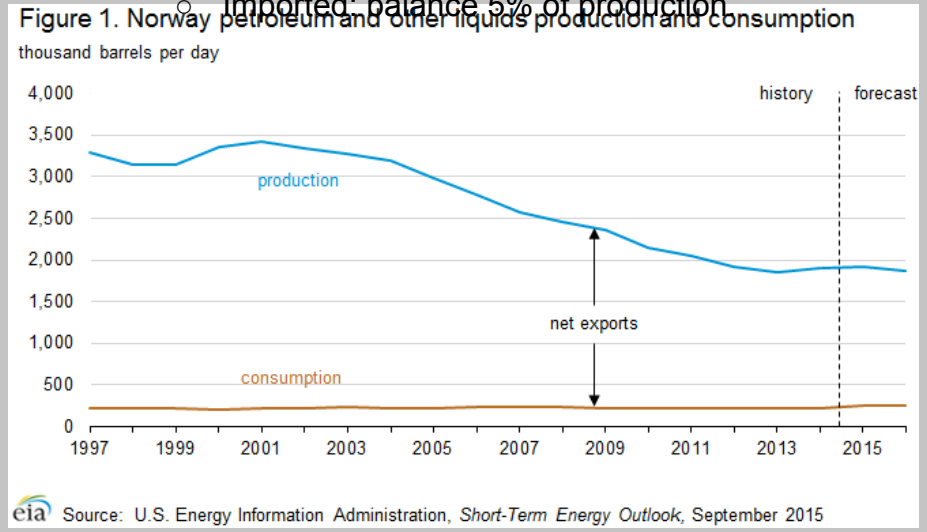
Planned projects, substantial:

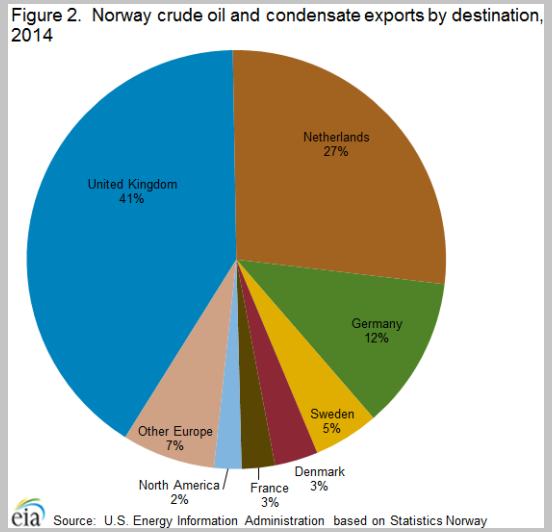
- Statkraft Wind Farm - 320 MW
- Markbygden Wind Farm - 1.37 GW

Norway: Oil, Energy History

- Crude Oil:
  - Net export 95% of production.
- Oil Products:
  - Imported: balance 5% of production

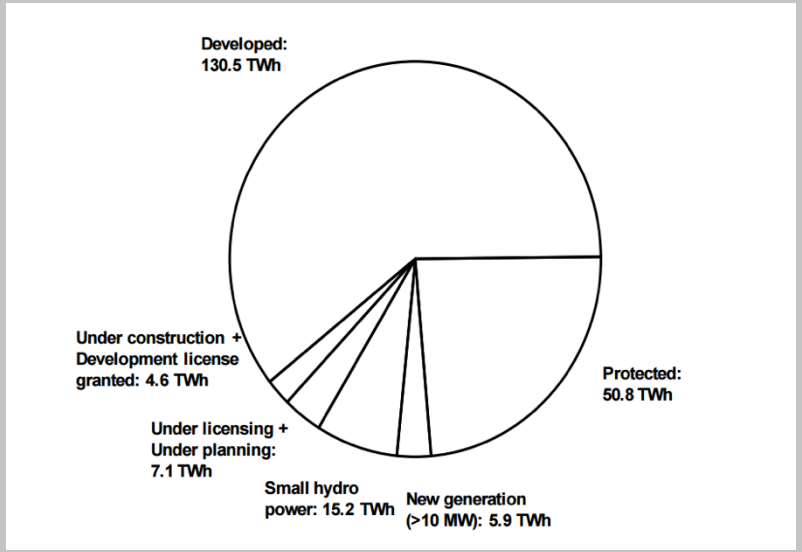
- Transportation energy:
  - 2015: 53 TWh
  - 2050: 66 TWh





Norway: Hydropower, Energy History

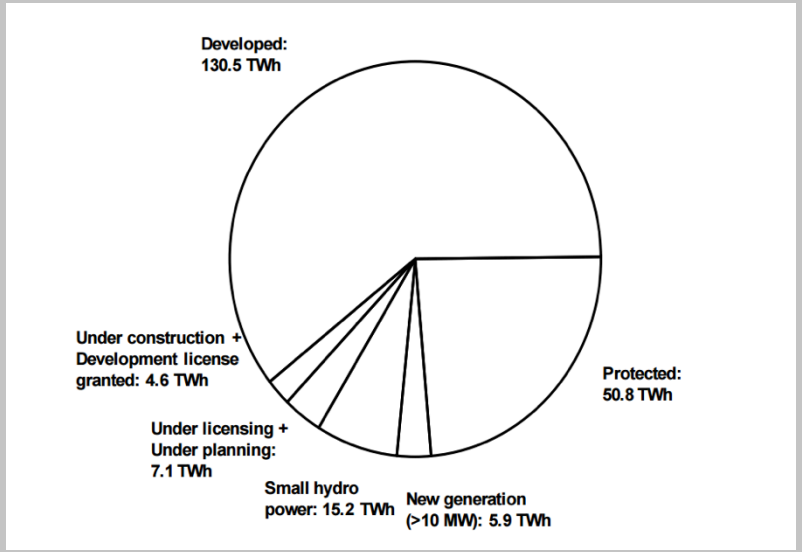
- Hydropower
  - Current Production: 142 TWh
    - Used for electricity generation only.
- By 2020, 67.5% energy consumption comes from renewable sources. (65% currently)
- Upgrading old hydro plants > 4-5 TWh more production.
- Climate Change in favor > precipitation, water reservoirs.
  - Increase ~5 TWh annually.



Hydropower Potential as of 2012, Norwegian Water Resources and Energy Directorate

Norway: Hydropower in Transportation

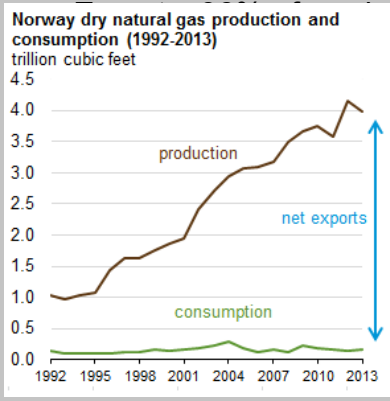
- Increase production
    - By ½ of current production.
- Geographically feasible to produce ~8% of the energy needed for transportation by 2050.
- Build ~25 new hydro plant.
    - Average capacity 300 MW.

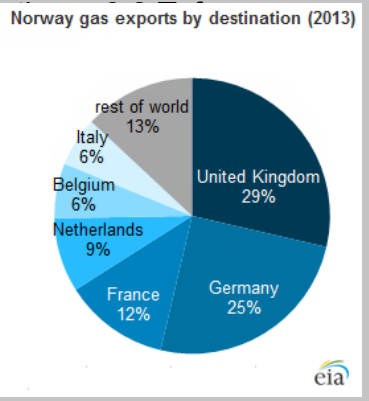


Hydropower Potential as of 2012, Norwegian Water Resources and Energy Directorate

Norway: Natural Gas, Energy History

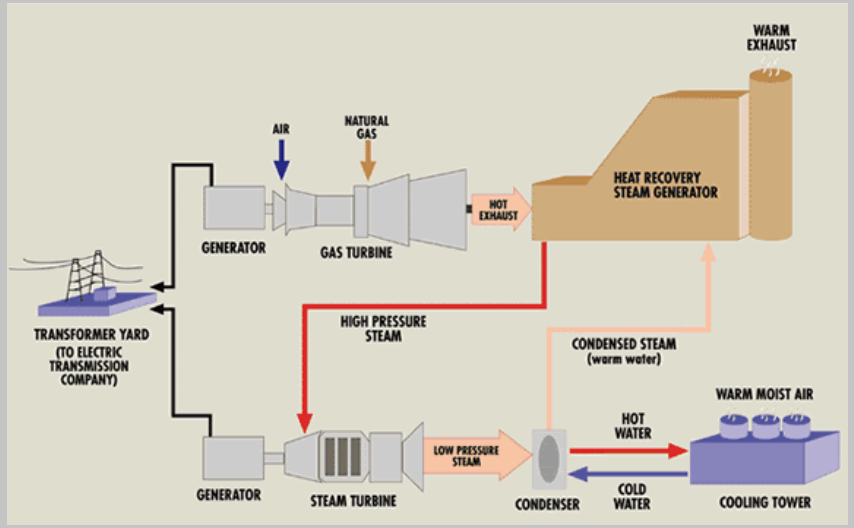
- World's 3rd NG exporter after Russia and Qatar.
- 21% of Europe NG needs in 2013. Mainly, UK, Germany, France, Netherlands, and Belgium.
- Production: 3.97 trillion cubic feet (Tcf) in 2013.





Norway: Natural Gas in Transportation

- Electricity Generation:
  - 11% total amount of exported NG.
  - Efficiency factor = ~55% in a combined steam and gas cycle power plant.Conclude:
  - Cost of natural gas reserved for transport will compensate for the price of un-needed imported oil and exported oil profit.



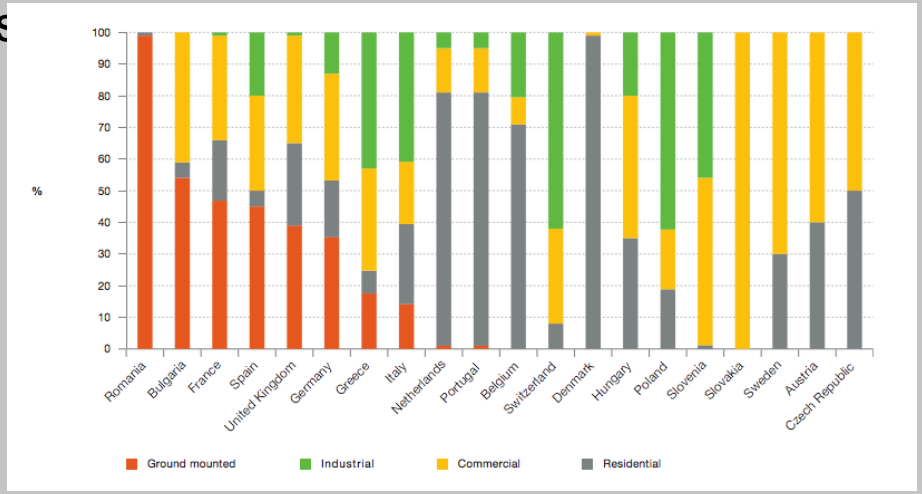
Denmark: Solar PV History

Set a goal to generate 200 MW of solar energy by 2020

- Achieved in 2012 (saw a twenty-fold increase in % growth)
- On track to install 3,400 MW by 2030

Of the installed solar PV, 98% was
period and low feed-in tariffs)

Gov't decreased incentives in 2013, but solar PV installation still increased

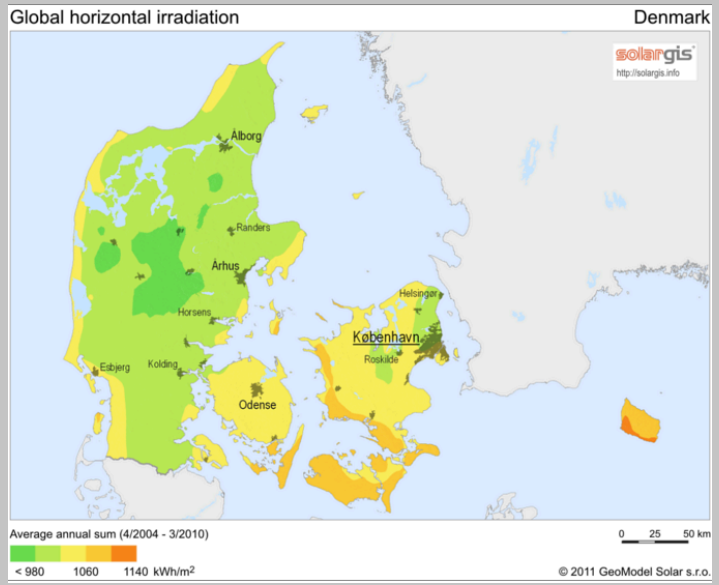


Source:
"Global Market Outlook for Photovoltaics 2014-2018". *www.epia.org*. 2014.

Denmark: Solar PV in Transportation

Assuming an average of 1,000 kWh/yr of solar irradiation

Demark would need 200 sq. miles of solar fields to fuel the transportation sector



Denmark Annual Irradiation (GHI)	1000	kWh/m^2 year
Solar Panel Efficiency	0.18	
Electrical Energy Generated / Area . Year	180	kWh/ m^2 year
Total Electricity Needed for Transportation (2050)	4.67E+10	kWh/ year
Area of solar panels needed	2.60E+08	m^2
Area needed (accounting for panel spacing)	5.19E+08	m^2
	519.34	km^2
	200.47	sq. miles
	128,299	acres

Source: GeoModel Solar. "Solar GIS: Denmark". 2011.

Denmark: Wind History

Commercial development began in the 1970's

Achieved 39% wind-derived electricity production by 2014

Further government plans to use wind for:

- 50% of electricity production by 2020
- 84% of electricity production by 2035

DONG Energy and other major players are heavily funding R&D projects to push the boundaries of offshore wind production

Can these goals be met? Would there be excess power to provide transportation energy?

Source: Denmark Ministry of Foreign Affairs. "A World-Leader in Wind Energy." *www.demark.dk*. 2015.

Denmark: Wind in Transportation

Using standard engines, Denmark would need:

- 8,000 Offshore Wind Turbines
- 19,000 Onshore Wind Turbines

Using electric engines, Denmark would need:

- 2,700 Offshore Wind Turbines
- 6,300 Onshore Wind Turbines

Assuming all energy produced is used for transportation, Denmark would need a 500% increase in turbine installation

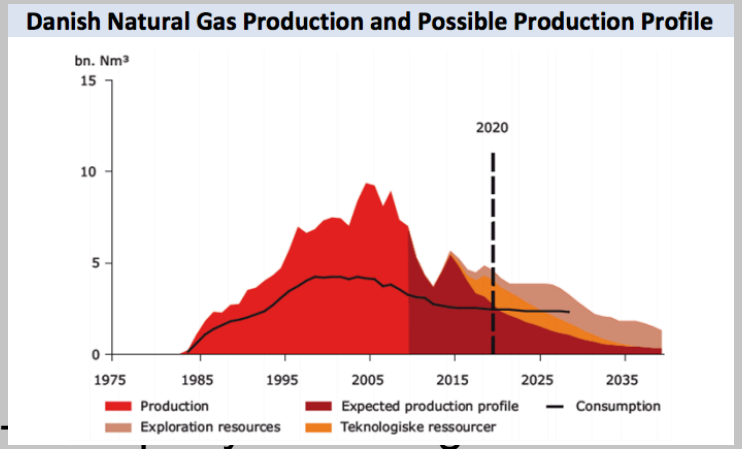
Denmark: Natural Gas History

1984- Production began in by extracting from reserves in the North Sea

2005- Peak production reached producing 10.4 billion cubic meters (bcm)

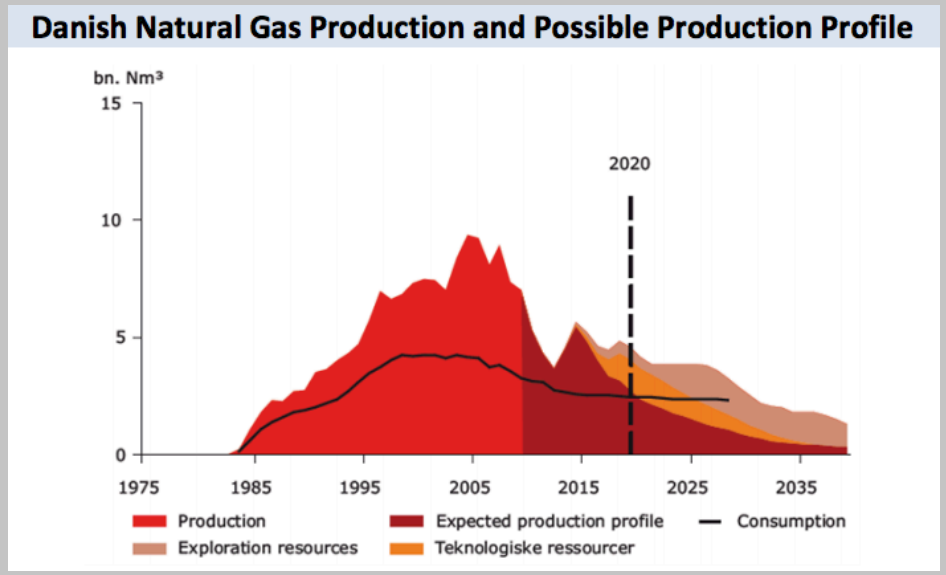
From 2010-2011, national production fell by 14% and consumption fell by 16%

Estimated decline by -



Source: IEA. “Oil and Gas Security: Emergency Response of IEA Countries.” www.iea.org. 2011.

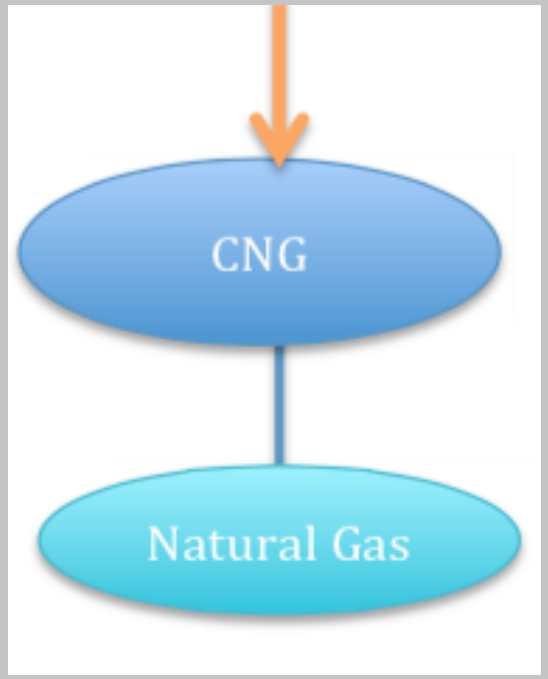
Denmark: Natural Gas in Transportation



- Denmark's Total NG Reserve is currently 37 Billion Cubic Meters (bcm)
- Achieving TET50 Would Require Over 13 bcm of Reserve
  - TET50 only accounts for 1 yr of consumption (< 3 yrs of supply)

Source: IEA. "Oil and Gas Security: Emergency Response of IEA Countries." www.iea.org. 2011.

3) Estimate Natural Gas Reserve and Transportation Energy Equivalent



For Sweden, Denmark, and Norway.

Sweden: Natural Gas

Only 3.6% of total energy needs.

Used for district heating and for petrochemical industry products.

No extraction of NG, all imported, mainly from Denmark.

Biogas is an emerging market.

Biogas requires energy density upgrade (through propane) before using gas transmission lines.

Sweden: Natural Gas

TET50 = 107.4 TWh

Assuming CNG's mpg similar to Gasoline's mpg.

- 2010 record volume of 1.6 Gm^3 was imported.
- Accounting for 19 TWh
- At 12 TWh/Gm^3, a total of 9 Gm^3 are required.

Is it feasible to import 9 Gm^3/year to power a CNG vehicle fleet ?

Sweden: Feasibility CNG fleet.

Decreased supply of its main provider, Danish Tyra Field.

Low energy density, limited travel range.

Insufficient gas transmission lines and fueling stations.

Elevated cost of home refueling.

Many emissions compared to EVs.

CNG is not viable for Sweden, and even for countries that have the NG resource, it is more practical to use NG for electricity generation to power EV's.

Import cost, compression cost, and fuel cost.

Energy Information Agency (EIA)

Norway: Natural Gas in Transportation

- Direct Compressed Natural Gas:
  - Case scenario: substitute Natural Gas for Gasoline.
  - Total Energy needs for Transportation: 237,191 TJ in 2050.
  - 1.2 billion cubic feet of natural gas is required to supply TET.
  - That is 0.031 % of total production of natural gas in Norway.

Denmark: Natural Gas History

Produces Over 200,000 TJ/yr (on a gross calorific basis)

Current NG Distribution:

- 42% Industry
- 41% Residential
- 13% Commercial & Public Services
- 4% Other
- **0% Transportation**

Since current N.G. Reserve is 37 bcm, future plans are in place to decrease annual production

Source: IEA Denmark Energy Balance-Natural Gas. Statistics. 2013.

Denmark: Compressed Natural Gas (CNG)

Gasoline engines can be converted to dual-fuel (Gasoline/CNG) vehicles

- Can cost up to $8,000/ passenger car

Advantages:

- Lower engine maintenance costs
- Approximately 28% lower lifecycle GHG emissions than gasoline vehicles
- Approximately 88% lower lifecycle GHG emissions than gasoline vehicles (if landfill biogas used)

Disadvantages:

- Cost to compress and transport not yet competitive with standard fuels
- Substantial infrastructure needed to become a viable alternative

Source: U.S. Department of Energy. "Costs Associated With Compressed Natural Gas Vehicle Fueling Infrastructure." www.afdc.energy.gov. 2014.

Denmark: Compressed Natural Gas (CNG)

Assuming CNG fuel economy is similar to gasoline:

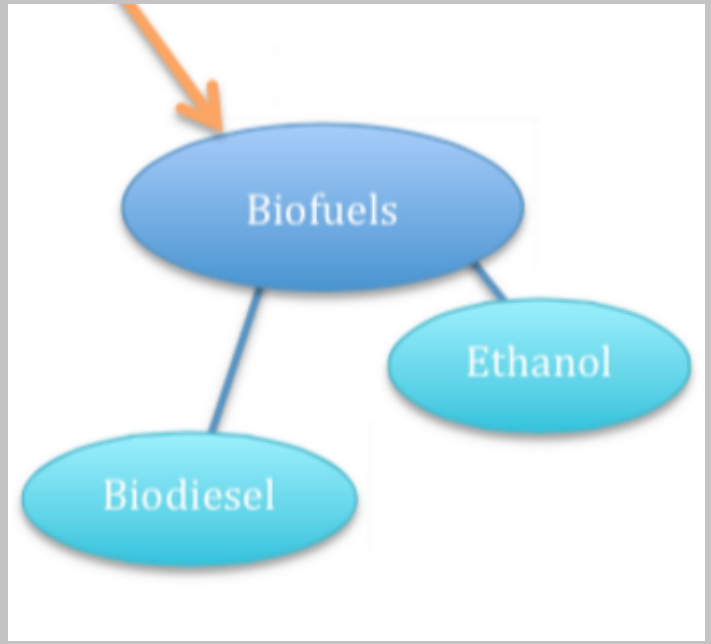
4.6 Billion Cubic Meters Would be Required to Meet Projected Demand (TET50)

Due to cost of compression, vehicle conversion, and necessary infrastructure:

N.G. supply should be reserved for electricity generation

Source: EPA. National Service Center for Environmental Publications (NSCEP). 2014.

4) Estimate Biomass Reserve and Transportation Energy Equivalent



For Sweden, Denmark, and Norway.

Sweden: Biofuels

Largest E85 Flexi-fuel vehicle fleet in Europe.

Largest ethanol bus fleet in the world, runs on ED95.

All heavily subsidized.

Production of Biogas from sewage on various municipalities, 23k gas vehicles, 104 public filling stations.

ED95 bus in Stockholm, running on a modified diesel engine. (www.greenfleet.info)

Sweden: Liquid Biofuels

Incentives for Liquid biofuels and FFVs:

Biofuels exempted from CO_2 and energy taxes, FFVs from congestion tax.

30% cheaper than gasoline at pump.

Auto insurance discount of 20% for FFV.

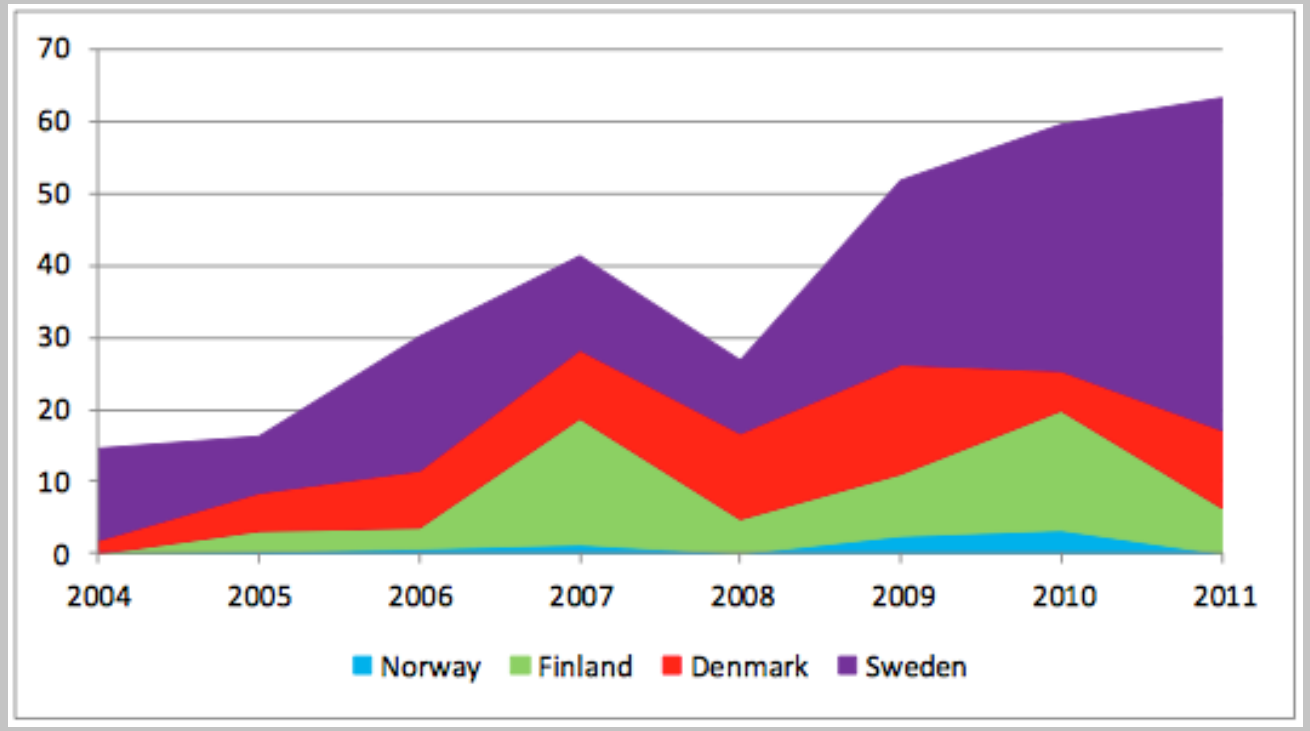
Bonus of USD 1,300 for FFV buyers.

Free parking permits.

Among others

Energy Information Agency (EIA)

Funding for Liquid Biofuels



1 € = 1.3 USD (2007)

Government RD&D funding of the production of liquid biofuels.

Eurostat

Feasibility

TET50 = 103.7 TWh

Supply from Liquid Biofuels (2013) : 4,131 TJ = 1.1 TWh

98% increase expected before 2050 to achieve FF-independent fleet.

Technological breakthroughs, especially Cellulosic Ethanol, will increase yield from crops.

Cellulosic Ethanol is expected to provide 190,000 TJ = 63 TWh from harvested crops, before 2040.

New fields can be sustainably harnessed.

Norway: Biofuels, Energy History

- Biofuels represent 1% of total renewables.
- Production: 17.16 GWh, Transport: 1.44 GWh. (~8%)
- Mainly CO2 taxes stimulate the use of biofuels.
- Biodiesel exempt from fuel tax and CO2 charges since 1999. Increase.
- E85 followed the exemption in 2006.
- Government incentives for flexi-fuel cars.

- Production of biofuels is linked to the production of fossil fuels in transport.

- Production of energy from biofuels is limited due to surplus in hydropower.

Source: Analysis of Biofuels Policy in the Nordic Countries Report.

Norway: Biofuels

- TET 2050 = 237,191 TJ
- Biofuel current production = 62 TJ
- Increase production by more than 3000%!
- With the current policies, fundings and incentives, biofuels production will increase relatively in small percentage. It will not be feasible to cover transportation needs by 2050.

Source: Analysis of Biofuels Policy in the Nordic Countries Report.

Denmark: Biofuels

10% Biofuel Energy Target by 2020

2012 - Began Transition to 2nd Generation Biofuels

- Increased R&D Funding
- Development of Necessary Infrastructure

Since 2005, Biofuels have been exempt from CO_2 emissions taxes

As of 2012, Denmark has subsidized biogas (used in CHPs) up to €15/GJ ($16.42/GJ)

Long-term commitment to developing biofuel technologies

Source: Olsen, D. Analysis of Biofuels Policy in the Nordic Countries. Top-Nest. 2013.

Denmark: Biofuels

No Solid Fuels or Biogases Used For Transportation

Liquid Biofuels: **253 ktoe** [ethanol and biodiesel]

TET50 (4,016 ktoe) → Increase Prod. By 1600%

Currently Imports 63% of Consumed Biofuels

Production: 111 ktoe
Imported: 192 ktoe
Exported: 25 ktoe

Not Feasible for 2050 without significant technological breakthroughs

Source: IEA. Denmark Energy Balance-Renewables and Waste. Statistics. 2013.

5) Feasibility of Fuel Usage by Consumption - Sweden

Nuclear: Phase-out attempted several times. Regulation forbids construction of new reactors.

Hydropower: Unharnessed rivers protected by law, or insufficient water flow.

Wind: No public opinion or governmental opposition. Many off-shore wind farms (39, 2,000 wind turbines), seems unlikely and expensive.

Compressed Natural Gas: Unfeasible, no national production, imports are expensive, energy security issues.

Biofuels: Feasible, great development but possible, resources available, Cellulosic Ethanol.

5) Feasibility of Fuel Usage by Consumption - Norway

Hydropower: Energy feasible could cover ~8% of TET50.

Natural Gas (Electricity): Feasible. By using ~11% of total exports could cover TET50.

Compressed Natural Gas: Feasible from total production to cover TET50.

Biofuels: Unfeasible due to surplus in other sources of energy and low current production.

5) Feasibility of Fuel Usage by Consumption - Denmark

Solar PV: Becoming increasingly popular energy source, but a 200 sq. miles of land would be needed to power the transportation sector

Wind: High wind speeds and off-shore potential make wind a viable option (to an extent)

Natural Gas (Electricity): Practical, but seems unlikely due to minimal national reserves

Compressed Natural Gas: NG reserve would be more effectively used to generate electricity for electric vehicles

Biofuels: Too much land required to meet demand of 2nd Generation Biofuels, but new technological advancements could become viable

6) Conclusions

Sweden:

- With developments in the Biofuels, Wind, and Nuclear industries Sweden can powe an oil-independent ground fleet by 2050.
- Liquid biofuels can achieve 42 TWh of thermal energy, 15 off-shore wind farms can generate 13 TWh of electricity with one nuclear plant another 8.76 TWh.

Norway:

- Oil-free transportation fleet could be reached by using a combination of hydropowe and natural gas to generate electricity; also in combination with CNG in hybrid vehicles.

Denmark: Should consider using a combination of Wind, Solar, and Biofuels

- TET50 (~47,000 GWh) could be achieved by installing 20 off-shore wind farms, 30 on-shore wind farms, 10 acres of solar panels, and consuming 600 ktoe of bioethanol/biodiesel by 2050.

Questions