Cogeneration 2050

the role of cogeneration in a European decarbonised energy system

COGEN Europe report

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Executive summary

It is difficult to argue that Europe can afford to waste energy. Increasing fuel prices, security of supply, increasing global competition and budget constraints all signal that Europe must shift to a more efficient energy future.

Using the principal of cogeneration when electricity is generated greatly improves the overall efficiency of the process. The electricity sector currently dumps over 50% of its input fuel as heat while making electricity in unabated thermal power plants. The scenario presented in this report asks the question “What can cogeneration contribute in 2050?” and based on published data proposes that in 2050:

- Cogeneration will have been extensively deployed for renewables, as sustainability of all resources becomes a priority. Renewables will be the dominant fuel used for cogeneration in 2050.
- Cogeneration will be the key in de-carbonising industrial heat encouraging European industry to improve its efficiency and remain competitive globally.
- Cogeneration will provide valuable balancing services and predictable power for a forward electricity market in a system with substantial intermittent renewables
- The integrated approach to energy supply embodied by cogeneration will reduce grid transmission losses while encouraging maximum use of local resources renewables and waste heat
- CHP makes the European Union’s decarbonisation scenario more cost effective and resource efficient

Introduction

It is difficult to argue that Europe can afford to waste energy. Security of supply concerns and the crucial role of energy in economic and political life signal that Europe must move to a highly efficient energy system. The European Union has committed to reducing greenhouse gas emissions to 80-95% below 1990 levels by 2050. The European Council has recognised that this commitment will require a (r)evolution in energy systems, and has tasked the European Commission with elaborating an energy **2050 strategy** providing the framework for the longer term action in the energy sectors.

The European Union's decarbonisation scenarios all share a need to improve efficiency and remove existing renewable resource constraints. This report highlights the role which cogeneration, as a key principal of energy efficient transformation, plays in achieving these objectives. It looks beyond the 2020 targets towards a 2050 horizon where the energy supply mix is radically different to today.

2050 Energy Supply and Demand in Europe

"What can cogeneration contribute in 2050?"

In its Impact assessment for the Energy Efficiency Plan 2011, the European Commission identified an additional economic potential for CHP of around 350 TWh of electricity, representing 15-20 Mtoe of primary energy savings per year, and avoided emissions of 35-50 Mt of CO_2.In order to test the impact of an energy scenario using substantial cogeneration, COGEN Europe and Delta Energy & Environment[1] charted the European energy flows in 2008 and produced a feasible scenario for possible energy flows in 2050[2]. The study used existing published projections for energy demand and supply mixes combined with available strategy documents and EU policy directions. The result makes visible the role of CHP which emerges under existing public domain strategies for supply changes, carbon reduction and a move to an efficient overall energy system.

What is cogeneration (or CHP)?
Cogeneration is the simultaneous production of electricity and heat, cooling or motion. The central and most fundamental principle of cogeneration is that, in order to maximise the energy output, systems should be designed to make use of the lower energy form (heat, cooling, motion) of the application. This is because these are local demands which must be met locally. In the case of heat this can be providing heat to an individual building, an industrial factory or a town/city served by district heat/cooling. Through the utilisation of the heat, the efficiency of cogeneration plant can reach 90% or more. Cogeneration therefore offers energy savings ranging between 15-40% when compared against the separate supply of electricity and heat from conventional power stations and boilers. The cogeneration principle is applicable to any fuel that goes through a combustion process and therefore is very well suited to scarce and valuable fuels such as biomass.

[1] www.delta-ee.com

[2] COGEN Europe has produced this report based on Delta's production of figure 1 (current 2008 sankey diagram) and figure 2 (the 2050 scenario Sankey diagram). Note that this 2050 view is simply one scenario, not a projection nor with an implication that other scenarios are not valid.

Energy Flows in the European Economy in 2008

The sankey diagram Figure 1 shows the 20,859TWh of total primary energy supply to Europe in 2008 as it moves through the various transformation stages (moving right across the diagram) towards end use. Fuel types have individual lines in the energy flows entering the European economy (on the left of the diagram) and moving through different transformation process to end use, or in the case of the down verticals to be lost from the system.

The energy mix in 2008 shows the dominance of fossil fuels in the mix but with a significant and growing quantity of renewables. Oil consumption is striking and its strong link to transport application is clear. Similarly striking are the large thermal losses from the traditional unabated thermal electricity generating processes on all fuels.

Total losses from the system in 2008 are 7754 TWh (37%) of primary energy input and these are largely from the electricity generating sector.

Cogeneration's contribution in 2008

The cogeneration principal is widely used today across Europe in a hugely diverse range of applications. Europe's industry receives process heat and buildings spatial heating and cooling from cogeneration, with electricity being generated for local use or being supplied to the grid. In 2008 as in 2011, roughly 11% of Europe's electricity is provided by cogeneration. Combined local production of heat and power saves a minimum of 10% primary energy compared to separate production, and with modern equipment the saving as stated by Denmark in its national potentials report on cogeneration is about 25%.

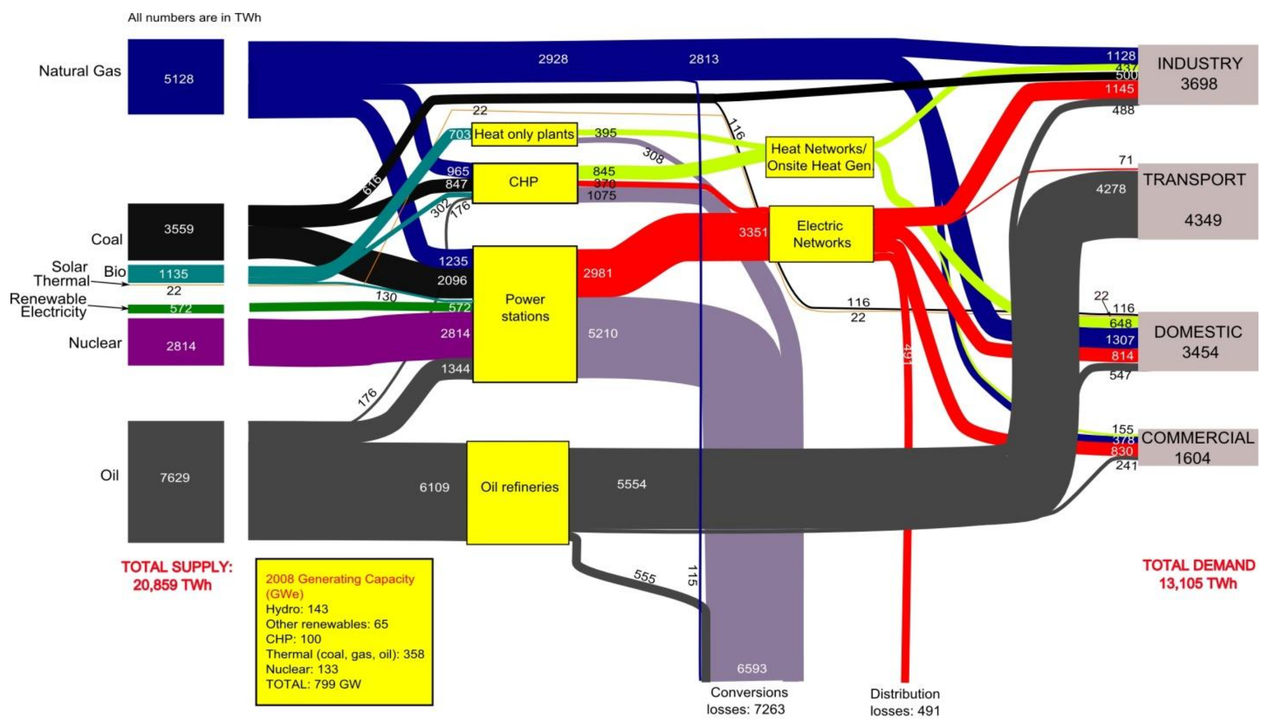

Figure1 **Energy supply and demand in Europe in 2008**

Cogeneration installations are also evolving and adapting to the emerging challenges of the heat and electricity markets. Growth in demand for cooling is now being met through trigeneration units that can supply buildings or industry with cooling as well as electricity and heat. Cogenerators, using short term heat storage to maintain efficiency and ensure the security of heat supply, are experimenting with more flexible modes of operation to meet the growing demand for controllable electricity production, allowing for balancing of intermittent renewables on the grid. Cogeneration in the kilowatt range is becoming commercially viable, offering the possibility to individual households of generating electricity locally, thereby relieving the large centralized plant of that role and taking pressure off the electricity grid, while covering all of the home's heating and hot water needs.

Energy Flows in the European Economy in 2050

This study is based on a feasible scenario of different primary energy supply sources in Europe's 2050 economy on the basis of published potential and market forecast studies and the migration of Europe to a low carbon economy (see Appendix 1). In the long term, if Europe takes a high efficiency route in its energy strategy, cogeneration could be far more widely deployed, with renewable fuels adopting cogeneration for efficiency and sustainability. The 2050 scenario projects what is possible if cogeneration overtakes conventional condensing power production as the preferred configuration for thermal electricity generation for energy efficiency and sustainability of renewable fuel reasons.

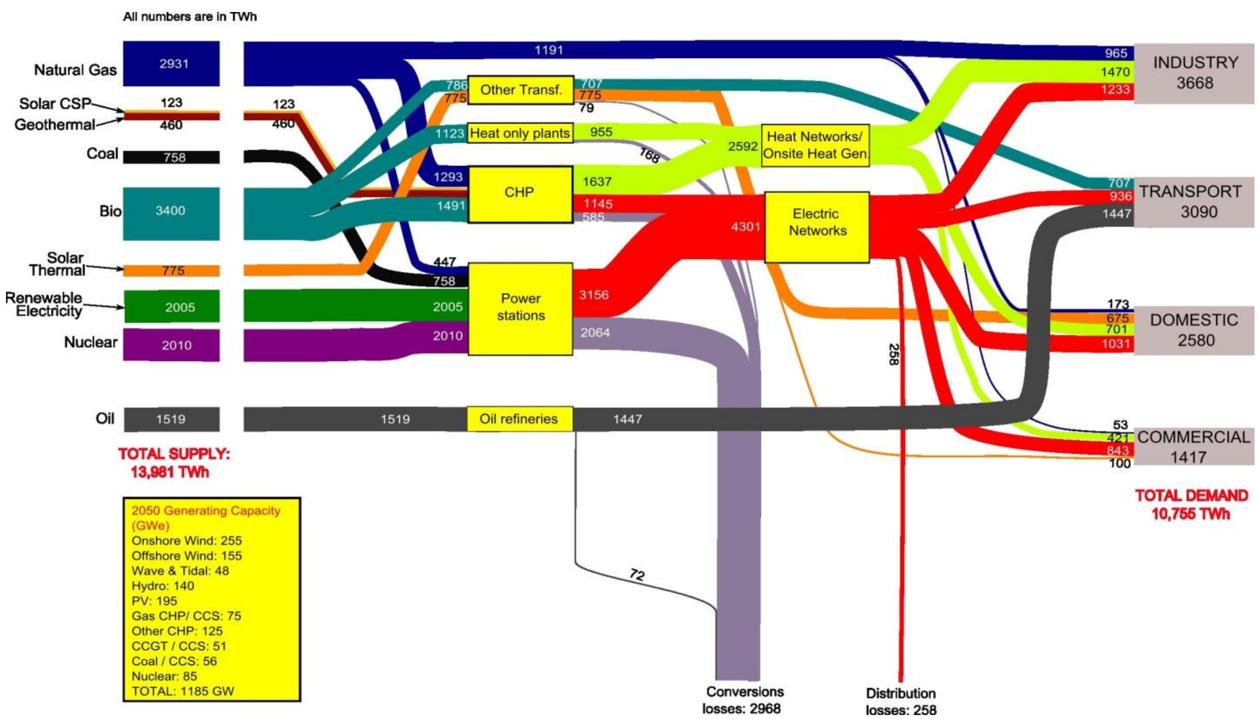

Figure 2 2050 Primary Energy supply and demand in Europefor the EU27 (in TWh)[3]

The 2050 sankey diagram (Figure 2) shows the scenario. It highlights the impact of the basic current European Union strategy assumptions: shift from fossils to renewables in electricity and heat generation, from oil to electricity in the transport sector and a shift to a high efficiency approach, including in power generation with the expansion of cogeneration. While total energy demand falls by 20% over the 2008-2050 period, from 13,105TWh to 10,755TWh, the declines in

[3] Sources: Existing data primarily taken from Eurostat, 2010. Confirmed by Eurelectric Power Statistics data and EC Energy Trends to 2030

fossil energy go hand in hand with a sharp rises in the use of bioenergy resources (biomass and biogas). Bio energy use in electricity generation is a thermal combustion process for which cogeneration is ideally suited. In 2050 a considerable percentage of this can be supplied in high efficiency cogeneration installations.

The two most striking elements of the 2050 sankey diagram are the reduced consumption of oil in the total system as transport makes switch to electricity and the hugely reduced losses from the electricity generating process through a combination of non-combustion renewables and CHP.

Cogeneration's contribution in 2050: Meeting future electricity demand

In this scenario, the amounts of electricity required by the European economy by 2050 are expected to rise by about 28% to over 4300 TWhe. Over the period, the make-up of generating technologies will certainly also shift as Europe pursues a low carbon energy supply target. There will certainly be limits to the extent to which cogeneration can be deployed and the sankey diagram reflects this, limiting the assumed penetration of co-located electricity and heat generation to 26%. With unabated thermal electricity generation there are always heat loss and the 2050 sankey diagram shows on-going losses from the electricity sector. While wind generation is attributed no thermal losses, nuclear and the remaining fossil fuel-based power generation dumps large quantities of heat.

Changes in fuel supply for electricity by 2050 highlight the decline in generators capable of supplying "base load" capacity. Base load is electricity generating plant which is reliably available and typically operates non-stop throughout the year, day and night. For historical reasons technologies chosen for base load have been those with the lowest operating costs and which are difficult to switch on and off. Nuclear and coal generation are typically base load. In 2011, the maximum potential base load capacity is 633 GWe, approximately 79% of total capacity. By 2050, with the change in fuel mix under this scenario, a maximum of 540 GWe approximately 46% total capacity could operate in base load mode.

The lower share of controllable generation capacity projected in the mix in 2050 is already today forcing a rethink of how the supply network can maintain reliability. Cogeneration thermal plants offer reliable controllable generating capacity maintaining the best characteristics of base load. In 2050 cogenerators from the kilowatt to megawatt capacity ranges will play a significant role, not only in electricity supply but also in electricity system services, balancing more variable renewables and providing predictable generation.

Generating electricity locally, in an embedded process also means lower distribution and transmission losses and minimizes the need for costly grid reinforcement and large cross border flows.

Meeting future heat demand

A clear assessment of the needs of all heat sector segments is necessary to choose the best form of supply in 2050. All heat requirements are not the same. The differentiation will become more and more apparent over time, between industrial high temperature heat and steam and low temperature heat in buildings as these two types of heat demand follow radically different supply paths over time.

Comfort in buildings: heating cooling and hot water

The increase in renewable energy supply in the EU's energy system plays a key role in future heat supply to buildings. The improved insulation standards in new buildings from 2020 onwards will drive a decline in overall space heating demand per square meter by 2050. Hot water demand is predicted to remain significant in new build, and the demand for cooling is expected to rise. The decline in heating demand per square meter is opposed by increased overall floor space in 2050.

Major deep renovation of the existing building stock will further decrease the space heating requirement of this sector over time, adding to the energy efficiency of the overall economy in 2050. Micro-CHP, which offers a high efficiency alternative to traditional boilers, is a cost effective solution in achieving high efficiency particularly in the more difficult to renovate buildings and less urban settings.

Deployment of cogeneration requires a more integrated thinking around energy use. The quantification of existing heat demand is closely linked to optimisation of the building shell itself. The integrated energy thinking which focuses energy thinking at a local level rather than an individual building level raises opportunities for identifying additional heat and cooling resources either from renewables or locally available source of heat from industrial or commercial processes. Grouping and linking supply and demand through heat networks can improve efficiency and integration of renewables, while heat pumps, which play a much more significant role in space heating in 2050, work well in combination with cogeneration.

Heat for industry and processes: steam and high temperature heat

Compared to the domestic heat sector, little attention has been paid in the literature to decarbonising high grade heat production which is in fact the backbone of Europe's industrial processes[4] .Migrating to a decarbonised solution by 2050 is central for European industry if industry is to remain in Europe. This must include a solution which is competitive and supports Europe's industrial ambitions. In current thinking, the stimulus of emitters paying for CO_2 emissions and reliance on carbon capture and storage are billed as the solutions for decarbonising the sector.

Industry is assumed to shift to a higher use of bio-fuels in response to the high cost of carbon. However there are real concerns about bio-energy scarcity, considering the large amount of fuel consumed by industry. More uncertainties surround the commercial deployment of CCS beyond large-scale coal-fired power plants in the required timeframe. The current study assumes that industry will adopt a cogeneration approach as the most cost-effective and available method of decarbonisation.

Considerable growth of cogeneration in industry is possible with the heat delivered in cogeneration mode trebling to 1470 TWh in industry by 2050, with decarbonisation reinforced by a fuel switch to a combination of low carbon natural gas and renewables.

CHP based on industrial heat loads ensures the most efficient use of primary energy. Using increased quantities of biomass and biogas within industrially-based CHP plants offers the unique advantage of generating zero emission electricity as well as zero-emission high grade heat. The two challenges which exist to wider industrial cogeneration in this form are to do with biomass

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[4] Steam is an important energy form in industrial applications and –according to the Commission's *Energy Trends to 2030 – 2007 Update report*- its use is projected to increase at 1.22% per year between 2005 and 2030, rising from approximately 75 Mtoe to 100 Mtoe in 2030.

(either solid or gasified) availability and affordability by mid-century, and an energy market which recognises the value of, and rewards, energy efficiency.

Heat from industry can be put to further use for further processing and space heating. Industrial cogeneration can provide a profitable new role for industry in a future of diverse and high efficiency energy supply.

By 2050 in a high efficiency scenario, CHP electricity is expected to represent around 26% of total electricity generation in the EU, increasing from 370 TWh in 2008 to 1145 TWh in 2050. This increase will be mainly driven by the rise in supply of renewable-based CHP electricity and associated heat with 44% of fuel being bio based. By 2050, nearly two thirds of the total energy input to CHP plants will come from renewable energy sources, with a projected 18% produced by non-combustion technologies such as geothermal and concentrated solar installations. The remainder is to come from the cleanest of fossil fuels: natural gas, all of which has CCS applied in this scenario.

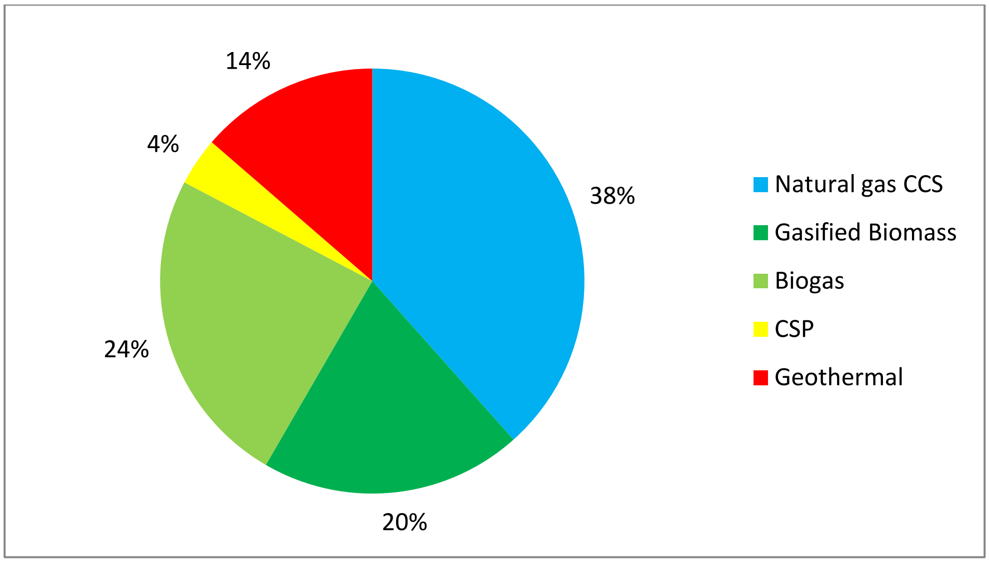

Figure 3 Share of primary energy inputs in CHP plants in the EU27 in 2050

Implications for EU energy policy

Supporting cogeneration technology: the need for change

Cogeneration has been on policy-makers radars for several years. However as an essentially distributed approach to the production of electricity, cogeneration is at odds with the traditional centralised model and several barriers remain to its wider use. Cogeneration has failed to grow in the past decade. Several elements must be addressed if cogeneration is to be more widely deployed:

A. Barrier removal

There is still a lack of transparency in many, many aspects of the authorisation procedures and tariffication of connecting new cogeneration to the electricity grid. This must be addressed in the interests of fairness and good business practise and to clarify investment opportunities.

Cogeneration in itself is an integrated approach to supplying heat and electricity. This means it is embedded and its primary customer is an economic or social function, a hospital, a neighbourhood or an industry. The cogenerator must have the ability to dispatch its electricity if it is to provide its high efficiency benefits to the energy supply system. Cogeneration requires priority of dispatch to satisfy both its heat and electricity customers, and cogenerators must work with network operators and regulators to develop acceptable models for doing so.

B. Integrated energy provision

By understanding the demand side of Europe's energy needs, COGEN Europe believes that Europe can further improve its overall energy efficiency.

There are several arguments in favour of an integrated approach:

- The role of heat and cooling networks, together with utilising waste heat streams, is a fundamental part of the new energy architecture and only becomes visible in a more integrated approach
- Distribution losses of heat and electricity are captured in a more integrated approach and are minimised by appropriate local use
- Optimisation of efficiency is often system specific and best designed and managed at the local level
- Many aspects of energy consumption are dictated by physical planning. This means that energy inefficiency is designed at the local level
- Integrated planning encourages the use of renewables

However, Europe's businesses, regulators and policymakers systematically assume separate supply of electricity and heat thus missing the efficiency potential of an integrated approach. The Member States through reporting under the CHP Directive 2004/08/EC have identified the potential to double cogeneration in Europe by 2020. Yet most Member States did not include micro CHP at all in their estimates, nor did Member States step outside their own experience or explore the possibilities from a fully demand side-led approach. Instead the majority of member states projected growth in industrial CHP where their history of cogeneration was in that sector and growth in district heating where that was their experience. No wider options were explored and a search for a demand led integrated approach was not evident.

The recent study "Building a Roadmap for Heat: 2050 scenarios and heat delivery in the UK" [5] confirmed the energy efficiency benefits of an integrated approach estimating that in a 2050 decarbonised electricity scenario for the UK it is possible to achieve additionally primary energy savings of 11% if CHP and other optimisation integrating technologies are used.

COGEN Europe concludes that in addition to vigorous short term deployment of energy efficiency foundation principals like cogeneration, Europe needs an approach to energy supply and demand which is integrated and allows long-term system

[5] "Building a Roadmap for Heat: 2050 scenarios and heat delivery in the UK" Imperial College and University of Surrey, April 2010.

Conclusion

CHP makes the EU's decarbonisation scenario more cost effective and resource efficient

The energy efficiency technologies needed to achieve Europe's energy efficiency goals are on the market today, with supporting supply chains and an existing European economic base. In the case of cogeneration the cost effectiveness of cogeneration in CO2 reduction rate is attractive in all studies[6] and the approach delivers a guaranteed saving in primary energy compared to separate production of at least 10%. This contrasts with many of the energy technologies required for the emerging 2030 to 2050 scenarios which face multiple challenges either technological, supply chain or infrastructure related, as well as societal to complete the transition. With very significant challenges to be overcome by the end of the next decade, regulatory support in favour of energy efficiency is necessary to drive the EU's economy towards lower primary energy use and maximal use of renewables.

Cogeneration technologies will have to contribute very significantly to the future European energy systems, both at a centralised and decentralised level, regardless of the type of fuel used. Already the European Technology Platform for Renewable Heating and Cooling acknowledge that moving forward an ever greater share of installations will operate in cogeneration mode, meaning more energy production from a limited amount of biomass in an optimised process. The same holds true for fossil-fired installations, until at least 2030 and likely beyond as CCS-fitted installations combine with cogeneration mode operation for ultra-low CO_2 emissions for both electricity and process heat production.

Member State reporting on techno-economic potential under Directive 2004/8/EC identified a further 100 GWe of installed cogeneration capacity in the EU by 2020. This would provide an additional 1000 TWh of heat and 455 TWh of electricity and would provide 46 TWh of primary energy savings annually by 2020. In the context of the EU's ambitious primary energy savings targets cogeneration contributes significantly to energy efficiency and the sustainability of supply in 2050. This potential however will only be realised if policy makers actively address the persistent economic and non-economic barriers to cogeneration and take a more integrated approach to energy supply and demand. The development of smart networks for electricity but also gas and heat networks should act as an enabler, at both the micro and macro level.

[6] In McKinsey (2009) "Pathways to a low carbon-economy" Green house gas abatement cost curve cogeneration rates as negative in most applications compare to the positive costs of many generating and even renewables technologies.

Annex 1: Study assumptions on Europe's economy in 2050

The joint study by COGEN Europe (the author of this report) and Delta Energy & Environment (which has produced figures 1 and 2 in this report) has looked at the energy flows at the European level come 2050. Specifically, this study aimed to highlight a credible role for combined heat and power plants (CHP) in a feasible 2050 energy scenario.

The study's scenario achieves an 85% reduction in annual CO_2 emissions compared to a 1990 baseline and results in a 33% energy efficiency improvement, assuming a 20% reduction in overall European energy demand from 2008 levels.

CO2 emission reductions

The above scenario results in an 85% reduction in CO_2 emissions compared to 1990 levels.

Energy demand, and primary energy figures

Primary Energy Input and Generating Capacity

TABLE 1: EUROPEAN PRIMARY ENERGY INPUT 2050
Primary energy in by fuel type, with rationale

Fuel		Energy Input (TWh)	Generating Capacity (GW)	Sources / rationale / assumptions
Natural Gas		**2931.0**		
	CCGT (CCS)	446.8	51	Not technically limited. Based in part on reference to European Climate Foundation Roadmap 2050 Scenario.
	Industrial CHP	963.6	55	Cogeneration as the foundation of Europe's 2050 low carbon energy policy. COGEN Europe, 2010.
	Community Heat CHP	329.8	20	
	Direct gas heating	1190.8	-	Remainder of heat demand that may be hard to meet from other sources, largely industrial heat demand.
Bioenergy / biogas / biomass		**3400.0**		Based on total sustainable bioenergy availability (3,837.9TWh excl. Imports - European Technology Platform on Renewable Heating & Cooling) and the European Environment Agency, 3,400TWh of sustainable resource by 2030.
	Biomass Heat only	1122.9	-	Available bio resource not otherwise deployed for CHP or transport.
	Biomass Gasification CHP (Industrial)	496.4	20	Cogeneration as the foundation of Europe's 2050 low carbon energy policy. COGEN Europe, 2010.

Biomass Gasification CHP (Community)	175.2	10	
Biogas CHP (Industrial)	262.8	45	
Biogas CHP (Community)	556.5	15	
Biofuel for transport	786.2	-	Potentially suitable for various forms of transport, in particular aviation and forms of road transportation that cannot be electrified.
Other renewables			
Onshore Wind	670.0	255	Potential studies (EWEA, ECF, Eurelectric) range between 247 – 350 GWe.
Offshore Wind	502.0	155	Potential studies (EWEA, Eurelectric) range between 125 – 250 GWe.
Marine	164.0	48	Potential ranges between 13 – 188 GWe. Eg 65 GWe based on EREC ('Rethinking 2050').
Solar PV	239.0	195	Potential ranges between 125 - 962 GWe (EREC)..
Hydro	429.2	140	Assumed no growth to 2050.
CSP CHP (community heat)	123.0	10	Cogeneration as the foundation of Europe's 2050 low carbon energy policy. COGEN Europe, 2010.
Geothermal CHP (Industrial heat)	223.3	10	Cogeneration as the foundation of Europe's 2050 low carbon energy policy. COGEN Europe, 2010.
Geothermal CHP (community heat)	236.5	15	Cogeneration as the foundation of Europe's 2050 low carbon energy policy. COGEN Europe, 2010.
Other Inputs			
Solar Thermal	775.0	-	Cautious potential estimate based on 'realistic' potential of 900 TWh, European Solar Thermal Industry Federation.
Nuclear	2010.4	85	Modest reduction from today's 133 GWe, partly in light of Fukushima incident.
Coal	758.1	56	All coal with CCS
Oil	1519.2	-	
Heat Pumps	576.9		Realistic view of heat pump potential based on National Renewable Energy Action Plans, ECF, EU Geothermal Energy council.

High level CHP Assumptions

These are based largely on Cogen Europe's report from 2010, 'Cogeneration as the foundation of Europe's 2050 low carbon energy policy'. Based on this context, CHP will make up 26% of electrical generation by 2050:

1. Installed capacity in 2050 not to exceed 200 GWe overall, with an approximate ratio of 2:1 industrial: non-industrial heat supply.
2. Load factors
    a. All industrial CHP (except CSP) – 85%
    b. All non-industrial (except CSP) – 60%
    c. CSP CHP – 35%
3. For natural gas CHP:
    a. Industrial CHP – electrical efficiency 42.5%, power to heat ratio 1:1
    b. Non-industrial CHP –electrical efficiency 31.8%, power to heat ratio 3:5
    c. CCS – all natural gas CHP has CCS applied, with a consequent 20% reduction in electrical efficiency.
4. For bio-based CHP
    a. Biogas CHP – electrical efficiency 42.5%, power to heat ratio 1:1
    b. Biomass gasification CHP – electrical efficiency 30%, power to heat ratio 30:55
5. Other CHP
    a. CSP CHP – power to heat ratio 1:3
    b. Geothermal CHP – power to heat ratio 1:2

Base load capacity in 2050

Today the maximum potential base load capacity is 633 GW, approximately 79% of total capacity. By 2050 we expect this picture to be very different. Under our scenario a maximum of 540GW, approximately 46% total capacity could be base load.

This confirms our view, and that of other scenarios we have seen, that there will need to be additional measures in place to ensure system balancing by 2050.

Energy Demand 2008/2050

TABLE 2: EUROPEAN ENERGY DEMAND IN TODAY AND IN 2050

Final energy consumption by sector in 2008 and 2050

Demand by sector	Today (TWh)	2050 (TWh)	% Reduction
Commercial	1604	1417	12
Industrial	3698	3668	1
Residential	3454	2580	25
Transport	4349	3090	29
Total	**13105**	**10755**	**20**

High level assumptions and rationale

- A final energy demand reduction of 20% on 2008 demand.
- Electricity share of demand increases from 21% of total demand to 37.5% of total demand
- Existing data primarily taken from Eurostat, 2010 – reinforced by Eurelectic Power Statistics data (2010) and EC Energy Trends to 2030 (2010).
- PES of 33% against 2005.
- Delta assessment of technical and economic potentials for a wide range of technologies is based on many single-sector and multi-sectorial analyses, including:
    - EU Energy [R]evolution – base and advanced scenarios (80% and 95% reduction in CO2 from 1990 levels). EREC, Greenpeace. 2010.
    - Eurelectric Power Choices. Eurelectric. 2010.
    - EU Energy Trends to 2030, 2010
    - ECF Roadmap 2050 (80% reduction scenario), 2010

TABLE 3: EUROPEAN FINAL HEAT DEMAND IN 2008 AND IN 2050

Final energy consumption by sector for heat in 2008 and 2050

Demand by sector (TWh)	2008	2050
Commercial	775.0	949.4
Industry	2553.2	2510.0
Residential	2645.1	2599.2

Delta Energy & Environment, 2011

Notes on Table 3

- In the residential sector, heat pumps account for 40% of heat demand. Flat residential heat (and cooling) demand reflects significant end use efficiency growth alongside growth in cooling demand and the number of residential units.
- Heat pumps account for 25% of total heat demand.
- Industrial heat demand remaining level reflects EU industrial energy demand growth with associated increase in energy efficiency.
- Growth in commercial heating and cooling demand reflects significant growth in EU non-industrial economic activity, much greater use of cooling – which more than offsets opportunity for efficiency growth.

Annex 2: Studies used and references

1. A path to sustainable energy by 2030, Mark Z. Jacobson, Stanford University (2010)

2. A Vision towards 2020-2030-2050, District Heating & Cooling + European Technology Platform (2010)

3. Biomass Energy Europe Project (2010)

4. Cogeneration as the foundation of Europe's 2050 low carbon energy policy, COGEN Europe (2010)

5. EcoHeatCool Project, WP1 Report (2006)

6. EU Impact Assessment EU Roadmap 2050, European Commission (2011)

7. EU Roadmap 2050, European Commission (2011)

8. European Ocean Energy Roadmap 2010-2050, Ocean Energy Association (2010)

9. Potential of Solar Thermal in Europe , ESTIF (2010)

10. Power Choices 2050, Eurelectric (2010)

11. PRIMES 2009 update, NTUA (2009)

12. Renewable Heating & Cooling European Technology Platform Geothermal Panel – Vision 2020 – 2030 (210)

13. RE-thinking 2050 report, EREC (2010)

14. Roadmap 2050 Project, European Climate Foundation (2010), http://www.roadmap2050.eu/

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17. Technology-oriented analysis of emission reduction. Kuder, Blesl (2010) IEW 2010, Stockholm

18. The Ecofys Energy Scenario, Ecofys (2010)

19. Trends to 2030 -2007 Update, DG TREN (2010)