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Department of Thematic Studies
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Carbon Capture and Storage: Major uncertainties prevailing in the FutureGen project

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Master's programme
Science for Sustainable Development

Master's Thesis, 30 ECTS credits

ISRN: LIU-TEMAV/MPSSD-A--14/007--SE

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2014

Acronyms and abbreviations:

ASU	Air Separation Unit
ARRA	American Recovery and Reinvestment Act
BAFO	Best and Final Offer
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization and Storage
CCGS	Carbon Capture and Geological Storage
CSFP	Carbon Sequestration Flagship Program
CSRP	Carbon Sequestration Regional Partnership
DA	Document Analysis
DOE	Department of Energy
ENGO	Environmental Non-Governmental Organisations
EPA	Environmental Protection Agency
FEED	Front End Engineering Design
GCI	Global CCS Institute
GHG	Greenhouse Gases
IEA	International Energy Agency
IGCC	Integrated Gasification Combine Cycle
IPCC	International Panel on Climate Change
LSIP	Large Scale Integrated Project/Power-plant
NETL	National Energy Technology Laboratory
NEPA	National Environmental Protection Agency
NRAP	National Risk Assessment Partnership
NGO's	Non-Governmental Organizations
ORNL	Oak Ridge National Laboratory
R & D	Research and Development
RFP	Request for Proposal
TA	Technological Assessment
US	United State of America
WEC	World Energy Council

Abstract:

Carbon Capture and Storage (CCS) is an old technology matrix with new concept to mitigate climate change while utilizing fossil fuels by advancing the technology. The various level of advancement in technology has been successfully demonstrated in some part of the world. However the technology has inherent uncertainty of not having commercial CCS plant. Efforts to make CCS commercially viable unfold uncertainties in numerous aspects of CCS technology. Beside the uncertainties in technology many barriers restrain CCS to become a successful climate mitigation technology. However the growing energy demand and urgent need to mitigate climate change through emission reduction favours CSS as transition to clean energy production. FutureGen 2.0 is the only large commercial scale CCS project, initiated in 2003 to test the commercial viability of the technology and to meet the U.S energy demands besides emission reductions target. The project resurrection in 2010 as FutureGen 2.0 after FutureGen termination in 2008 provides an opportunity to understand and analyse numerous uncertainties. However through document analysis only major three uncertainties i.e. policy and regulatory, economic and financial and public acceptance uncertainties are identified and analysed. The interlinkages between these uncertainties are also analysed. The study results show that above uncertainties constrained the project engendering new uncertainties i.e. timeframe uncertainties. This study also provides an insight about the sustainability implication of CCS by evaluating economic, environmental and social impact of CCS technology. It is still early to term the CCS as Sustainable technological innovation however for many years CCS would upset and restrain investment in other clean energy technologies like Renewable technology system. This study gives an input in sustainability of CCS and technological assessment study. This study is helpful in managing uncertainties and planning new CCS projects.

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1.1 INTRODUCTION:

Carbon Capture and Storage (CCS) is recently visualised as a significant climate mitigation technology. Although CCS has been previously used for Enhance Oil Recovery (EOR) however its implication to reduce carbon emission is new concept. A great anticipation in CCS technology has been seen in recent decades due to high optimism by various policy makers and CCS experts. CCS prompted as a climate mitigation technology after Intergovernmental Panel on Climate Change (IPCC) special report on carbon dioxide (CO_2) capture and storage in 2005. There is a keen interest of multinational companies in CCS technology, further many environmental NGOs (ENGOs) have also shown positive response towards CCS development (Evar, Chiara & Scott 2012; Global CCS Institute (GCI) 2012; International Energy Agency (IEA) 2010 & 2013). Many demonstration projects of CCS technology have been started in numerous countries, mostly in developed nations of the world with a notion of reducing CO_2 emissions. About 75 large scale integrated CCS projects (LSIPs) have been identified since September 2012 (IEA 2013; GCI 2012 & 2013; Javedan 2013).

The growing interest in CCS has resurrected the use of fossil fuel especially coal (Hansson & Bryngelsson 2009; Raupach et al. 2007; Stephens 2006). The notion of climate change mitigation while utilizing fossil fuel has made CCS as a forefront climate mitigation technology. However Hansson and Bryngelsson (2009, p. 2274) pointed out that CCS technology has inherent uncertainty of lacking commercial scale project. Efforts made toward CCS commercialization unfolded various economic, financial, political, technical and societal uncertainties in CCS technology (Davies, Uchitel & John 2013; Markusson et al. 2012; Markusson, Kern & Watson 2011). CCS experts although anticipate development of large commercial size CCS projects feasible however various identified barriers have limited CCS scope (Davies, Uchitel & John 2013; Hansson & Bryngelsson 2009; Oak Ridge National Laboratory (ORNL), 2007).

The development of CCS is considered to have sustainability implication at both regional and global level. Numerous analysts with diverse perception have pointed out environmental, health and safety risks of CCS implication besides numerous uncertainties in technology (Birkholzer & Zhou 2009; Corsten et al. 2013). One important implication of CCS development is that CCS as climate mitigation technology is costly option and is argued to restrain investment in other clean energy technology. Further application of CCS to coal and other fossil fuel seems to lead to carbon lock-in, making it difficult to other actors involve in energy sector to compete (ORNL) 2007; Unruh & Carrillo Hermosilla, 2006). Many policy makers and CCS experts are optimistic about the CCS as carbon emission reduction technology and pursue CCS as a sustainable option in climate mitigation portfolio (Butt, Giddings & Jones 2012; IEA, 2013; Hansson & Bryngelsson 2009). However analysing the uncertainties and sustainability implications of CCS technology it is still early to mention CCS as sustainable option in climate mitigation technology portfolio.

FutureGen 2.0 project is the only commercial efforts considered to be a technological innovation in terms of climate mitigation technology and could lead to sustainable utilization of fossil fuels. However the project remained suspended due to emerging uncertainties technology. The project resume activates towards development of FutureGen 2.0. Therefore evaluating sustainability of FutureGen 2.0 is important and study is required to understand how FutureGen 2.0 progressed beside managing uncertainties.

1.2 PROBLEM FORMULATION

Among fossil fuel coal is considered an affordable fuel for energy and power generation as it is readily available with large reserve around the world and has minimum issue of accessibility (Sovacool, Cooper & Parenteau 2011; Hansson & Bryngelsson 2009). According to World Energy Council [WEC] (2013) about 7.5 billion tons (Bt) of coal and 3.9 Bt Oil were recoverable at the end of 2011 and expected to increase to 10 Bt and 4.5 Bt respectively. However fossil fuel and especially coal is a major source of climate change due to high rate of emissions of carbon contents and is considered Hazardous fuel for climate and environment (Raupach et al. 2007; Schrag 2007). Therefore Coal power plants with CCS technology are anticipated as a significant source of energy production while reducing high proportions of carbon emissions (Russell, Markusson & Scott 2012; IEA 2013).

According to IEA (2013) to achieve 2 ˚C scenario (also referred as 450 scenario), about 22% of the CO_2 emission reduction by 2035 could occur only by adopting CCS to 32 % of large scale coal power plant. Such development consequently would limit temperature increase to 2 ˚C (IEA 2013; Lipponen et al. 2011).

CCS technology have been adapted at a fast pace in developed world during last decade. Up till now eighth large scale integrated projects are operational. However these projects operate at industry (most of them other than power industry) that is less technically demanding and more economically viable (IEA 2013; Van Alphen et al. 2007; Van Alphen, Noothout, Hekkert & Turkenburg, 2010; Lipponen et al. 2011). A wide range of studies have shown that applying CCS technology to energy and power generation sector has yielded technical, economic, legal and regulatory uncertainties (Hansson & Bryngelsson 2009; Blyth et al. 2007; Bowen 2011; Wall, Stanger & Santos 2011). Uncertainties in CCS application to energy and power generation sector vary due to technological diversity and fuel source (IEA 2013; Sylvan 2012; Van Alphen et al. 2007).

Many projects have been cancelled due to overlooking these uncertainties. For example, a £ 1bn Longannet Project was anticipated to operate on the third largest coal power plant in Europe was cancelled when financially uncertainties were uncovered. The project was declared commercially not feasible and ultimately cancelled. Similarly Coolimba Power project also based on coal power generation was cancelled due to financial constrains. The Sweeny IGCC Power Project was cancelled due to lack of policy and regulatory structure and financial uncertainties which lead to an organization split (GCI 2013; Javedan 2013; ZEROCO$_2$.NO 2012). Moreover Sask Power and FutureGen projects remained suspended for more than five years due to lack of financial support and policy incentive (Javedan 2013; Sylvan 2012; Stephens, Markusson & Ishii 2011).

Most of the CCS projects were coal based fuel projects with high number of small scale and low number of large scale. However the overall objective was to attain a commercial level confidence by successful implementation of these projects. Although most of the large scale project faced failure however it also raise the concerns related to uncertainties and urge for further research in enhancement of knowledge related to uncertainties in CCS.

The greatest benefit of CCS is the climate remediation by avoiding CO_2 emission, mostly ignoring the broader socio-economic and environmental impacts. The implications of technology exacerbate the viability of CCS due to the complex nature of technology and accidental leakage treat. It is also pointed out that CCS might restrain investments in other clean energy technology beside the development of CCS is being expensive (Stephens & Jiusto 2010; Van Alphen et al 2007). Environment, health and safety risks from the over all CCS system and specifically from CO_2 storage site further raise the concerns related to sustainability implication of CCS technology (Birkholzer & Zhou 2009; Corsten et al. 2013; Newmark, Friedmann & Carroll 2010). Numerous energy experts have predicted that CCS might lead to Carbon lock-in. The CCS critics predict that the huge investment in CCS technology would continue fossil fuel regime till the beginning of next century (Markusson & Haszeldine 2008; Unruh & Carrillo Hermosilla 2006). Although CCS can be viewed as technological innovation in climate mitigation matrix however barrier to change into a low carbon socio-technological regime could raise concerns related to sustainability implications of CCS (Hansson & Bryngelsson 2009; ORNL 2007; Vergragt, Markusson & Karlsson 2011). The barriers to such change are due to mature socio-technological regime of fossil fuel energy and its component from drilling till financial market and stock exchange.

The efforts to resolve uncertainties are mostly political and cooperative ambitions that anticipate the necessity to make CCS a commercially viable climate mitigation technology (Butt, Giddings & Jones 2012). The uncertainties and barriers to change ensure that although CCS technology is available but it is not mature technology (Vergragt, Markusson & Karlsson 2011, pp. 283). As mentioned above the coal based CCS projects, mostly large scale with the intentions to gain commercial confidence has been terminated due to emerging uncertainties. FutureGen project was the only commercial CCS project that was redesigned as FutureGen 2.0 in 2010 (Javedan 2013). FutureGen 2.0 project is also based on Coal as source of fuel that has been abandoned due to emergence of numerous uncertainties and barriers to change (Sylvan 2012, pp. 188). However FutureGen 2.0 is the only surviving project that persists in managing uncertainties and enhancing knowledge related to CCS technology. FutureGen 2.0 though still is in construction phase has nous knowledge about commercial scale CCS technology and uncertainties that prevails in CCS. Therefore this study aims:

1.3 Aim

This study aims to:

1. Analyse the three major uncertainties that prevailed in the FutureGen project and analyse how FutureGen progressed to FutureGen 2.0.

The three major uncertainties taken in consideration are: economic and financial, policy and regulatory and public acceptance.

1.4 Research Questions

1. What are the dominating uncertainties in economic and financial, policy and regulatory and public acceptance aspects of FutureGen project?

2. Inter-linkages between uncertainities?

3. How FutureGen 2.0 managed uncertainties?

1.5 Study Motivation

An extensive work has been done to show CCS as one of the future climate mitigation technology (IPCC 2005; Kaarstad, Berger & Berg 2011; Russell, Markusson & Scott 2012; Van Alphen, Hekkert & Turkenburg 2010). Limited work has been done concerning uncertainties and sustainability issue of CCS. Almost no work has done to analyse the uncertainties in FutureGen 2.0 project and to look CCS first commercial project from sustainability perspective. I argue that analysis of above mentioned uncertainties would provide understanding about the sustainability implications of CCS by scrutinizing economic, environmental and social impact of CCS technology system. This would cover the study gap by imparting knowledge in the sustainability study of CCS. Further the intense need for emission reduction and growing energy demand strengthens the need to analyse major uncertainties prevailing in world's only commercial CCS project. Therefore this study would not only increase our understanding about major uncertainties but it would also enhance the knowledge related to uncertainties management and overall sustainability implications of CCS technology system.

1.6 Study Limitation

This study is limited to analyze three major uncertainties due to time and cost limits. Beside the limited time and cost of the study economic & financial and policy and regulatory uncertainties are considered as the preliminary barriers to commercialization of CCS technology (Davies, Uchitel, Ruple, 2013). Public acceptance is considered as precondition and necessary for gaining public confidence and implementation of CCS (Van Alphen et al. 2007; Greenberg et al. 2009; Wade & Greenberg 2009) and therefore is taken into consideration. The three major uncertainties remained the primary cause of terminating numerous projects (Sylvan 2012; Davies, Uchitel, Ruple, 2013; Blyth et al. 2007; Bowen 2011).

The remaining four uncertainties identified by Markusson et al. (2012) are related to over all CCS technology at global level. For example variety of pathway uncertainty is related to competition among technology variants and what technology and when it will win out? Similarly scaling up and speed of development and deployment uncertainty is related to the capacity of CCS supply chain and urgency for its deployment. For the uncertainties related to integration of CCS systems and Safe storage I argue that these two uncertainties come under the policy and regulatory aspect of FutureGen 2.0. Although further study is encouraged for each individual uncertainty with ample time and financial resources However we argue that looking FutureGen 2.0 from sustainability perspective would cover both risk related to integration and storage site.

1.7 CCS TECHNOLOGY

Carbon Capture and Storage is also known as geological sequestration, or geo-sequestration, or carbon capture and geological storage (CCGS) or carbon dioxide capture and storage. The concept of CCS is capturing carbon from fuel utilization, separating the clean energy stream and then stored the captured carbon in a safe underground storage (Evar, Chiara & Scott 2012). CCS system can be segregated in to three component based on function i.e.:

1) Carbon capturing at industrial level through either pre-combustion, or oxy-combustion or post combustion.
2) Followed by transportation of captured carbon either through underground pipeline or railroad or ships (depends on the feasibility and storage sites) to
3) The storage site, where it is safely stored deep underground impermeable rocks.

The technology of Carbon Capture and storage is as old as the petroleum industry. CO_2 injection technique has been reported to be used commercially for enhancement of oil recovery since 1972, in countries like U.S, Turkey and Canada (Evar, Chiara & Scott 2012; Massachusetts Institute of Technology (MIT) 2007; IEA 2013). However the technology has not been tested on large scale Coal power plant (Hansson & Bryngelsson 2009; Nykvist 2013; MIT 2007). CCS is no doubt an old technology however its application in climate mitigation portfolio is a new experience (Evar, Chiara & Scott 2012; MIT 2007).

1.8 UNCERTAINTIES IN CCS

Previous studies shows encouragement for large commercial scale CCS project. The demand for commercial nature CCS project is due to high optimism in technology. However some analysts believe that there are various uncertainties in CCS technology. As pointed out by Buhr & Hansson (2011) that CCS is difficult to predict as viable technology in mitigation portfolio due to its numerous characteristics. Previous experience of CCS development also shows that numerous large-scale projects have been concealed due to various uncertainties in CCS technology (Nykvist 2013).

Markusson et al. (2012) provide a detail account of almost all uncertainties that prevail in CCS. These uncertainties range from socio economical to technical aspect of CCS technology; while an uncertainty is defined as ‘lack of knowledge about an important aspect – be it technical, economic, political etc. – of CCS technology and wider social-technical system with which it co-evolves’ (Markusson et al. 2012, p. 905). Markusson et al. (2012) further discuss change in approach towards uncertainties while developing new technology.

They mentioned about the role of society and wide range of actors in technology evolution. They describe how uncertainties should be dealt according to second Technological Assessment (TA) period:

> Uncertainties in developing new technology remained centre of attention in Technological Assessment (TA) studies. However with the wave of second TA period it is believed that technology co-evolve with the development of society and the involvement of broader range of actors. The co-evolution has changed the viewpoint regarding TA from distance observation to the involvement of development and governance. Similarly the stance also changes from predicting uncertainties to unpretentious persistence on understanding the uncertainty that explores various potential future pathways for change (Markusson et al. 2012, p. 913).

Markusson et al (2012) implies from the above discussion possibilities of multiple future developments; mentioning that such possibilities might either become hesitation for development or requirement i.e. the hesitation by the actors for further development and adaptation of technology or the requirement of adaptation of technology and the wider socio-technical system to contain these uncertainties.

1.9 US INITIATIVE OF FIRST LARGE COMMERCIAL SCALE CCS PROJECT

The US energy profile signifies the urgency of CCS development despite the fact that numerous uncertainties cause failure to many CCS projects. US on one hand is a coal rich country with huge dependence on coal for human prosperity and to keep the modern lifestyle (WER 2013, p. 1.31 & 2.8) While on the other hand it has the highest rate of CO_2 emission, which is expected to increase further in coming years (Damiani et al. 2012; Shcrag 2007). Great shares of these emissions come from coal utilization (Damiani et al. 2012; Raupach 2007; WER 2013).

Therefore in pursuit of emissions reduction besides energy security U.S Department of Energy (DOE) initiated Carbon Sequestration Programme (CSP) in 1997 (Damiani et al. 2012; Litynski et al. 2013; National Energy and Technology Laboratory (NETL) 2007). The CSP is managed by National Energy Technology Laboratory (NETL) and focus on research and development (R&D) beside global collaboration in the field of CCS technology (Litynski et al. 2013; NETL 2007). The CSP R&D look toward the commercialization of geologic storage sites, while American Recovery and Reinvestment Act of 2009 (ARRA) is supposed to fund the crosscutting project intended to develop carbon capture, utilization and storage (CCUS) in U.S complement CSP (Litynski et al. 2013, p. 6528).

1.10 FutureGen 2.0 brief description

In 2003 FutureGen project was initiated under the Agency Action requirement based on National Energy Policy (NEP) recommendations (Stephen, Markusson & Atsushi 2011; NETL 2007). The project was intended to fulfil both research activities and commercial coal based CCS plant (NETL 2007). However as mentioned in the section 1.1 and 1.2 the project was terminated due to lack of financial and policy incentives. The project was resurrected in 2008 as FutureGen 2.0 however the course of the project was undetermined until the project was redesigned in 2010. In this study the term 'FutureGen' is used for project before termination while 'FutureGen 2.0' for project after project redesigned in 2010.

The FutureGen 2.0 project is the only large scale commercial CCS project. The project intends to produce 200 MW-electricity through advancing Ameren Energy Resource's Coal power plant in Meredosia III, Illinois, with oxy-combustion technology. The Meredosia III power plant is now known as Meredosia Coal complex with carbon capturing technology (Greenberg & Hund 2010; Roger 2012; GCI 2012; ZEROCO_2.NO 2012).

The technology would enable to capture 1.3 million tons of Carbon dioxide (CO_2) per annum. This constitutes around 90% of CO_2 emissions, and then transported through safe and proven pipeline technology to Morgan County near Ashland to store 30 miles underground in deep saline formation (FutureGen Alliance 2013c; Javedan 2013; ZEROCO_2.NO 2012). To build a commercial confidence in the technology and gain public trust the project aims to provide performance and emissions data by constructing and developing visitor complex near to CO_2 storage site for research activities and visit (FutureGen Alliance, 2012; ZEROCO_2.NO 2012).

FutureGen 2.0 alliance is non profit consortium formed with the aim to benefit the public interest and the interest of science through research. The FutureGen 2.0 alliance goal is the development and demonstration coal technology with near zero emission (FutureGen Alliance, 2013a; MIT 2007). Members of the alliance comprise of Coal Corporation, Coal Produces, Coal Equipment Supplier and U.S. Department of energy (DOE), constituting a government and Private company partnership (FutureGen Alliance, 2013b; Ryser 2011). The U.S DOE and State of Illinois are at forefront to make FutureGen 2.0 a reality (Wernau 2011). Beside the U.S. DOE the industrial member of FutureGen 2.0 Alliance include Alpha Natural

Resources, Anglo American, Joy Global, Peabody Energy and Xstrata Coal (FutureGen Alliance 2013a & 2013b).

1.11 Background Studies

Hansson and Bryngelsson (2009) have inquired the expert views about the uncertainties in CCS and possibilities of CCS technology. Their study identified a visible gap between the optimism in CCS technology and uncertainties that prevails. They argue that:

> Gap between uncertainties and optimism surrounding CCS technology is neither unique and not necessarily be considered a paradox, but a generic phenomena when developing new complex energy technologies" And therefore should neither be taken as a reason to hamper developing CCS technology nor as a basis for ignoring uncertainties. Therefore uncertainties in CCS are important to study for avoiding failure in CCS development (Hansson & Bryngelsson 2012, p. 2275).

Blyth et al. (2007) analyse the IEA results related to investment risk associated with climate change policy. Their study results show that policy uncertainty is an exogenous risk for corporations and recommended policy certainty by reducing the risks. Keppo & Van der Zwaan B (2011) used bottom up energy system model TIAM-ECN- a stochastic version to study the impact of storage potential and climate control target uncertainties on long term emission abatement. To attain transparent changes caused by uncertainties a set of scenario was also run. Their study results show that a strategy is required that should emphasize on stringent potential mitigation goal. Their study show more pessimistic result in term of storage capacity limiting the CCS role prior to 2050 beside the high CO_2 emission price.

Wall, Stanger & Santos, S (2011) found out that financial & economic, policy & regulatory and public acceptance uncertainties are of foremost barriers in implementation of oxy-combustion technology for rapid commercialization of CCS than technical uncertainties. Their study result also show that the successful implementation of large scale oxy fuel project would highly impact the technology comparison and adaption. Davies, Uchitel, & John (2013) empirically evaluated various uncertainties in developing large commercial scale CCS project in United State (US) and identified economic & financial and policy & regulatory uncertainties as primary uncertainties that hinder CCS commercialization. Markusson et al. (2012) provide a detailed account of uncertainties and identified seven key uncertainties in CCS technology. The seven key uncertainties are interlinked with each other and consistent with over all development of CCS technology. Markusson et al. 2012 developed a framework for analysing these uncertainties. The Markusson et al. (2012) framework of uncertainties is discussed in next chapter in detail.

Butt, Giddings & Jones (2012) studied CCS contribution to environmental sustainability and concluded that CCS is sustainable technology for both current and future generation. Similarly studies have been conducted to see the environmental risk with variant results (Corsten et. al. 2013; Newmark, Friedmann & Carroll 2010). A study conducted by Oak Ridge National Laboratory (2008) for DOE; US identified several barriers to deployment of climate mitigation technology that reinforce carbon lock-in.

Vergragt, Markusson & Karlsson (2011) provided the detail account of possibility of carbon lock-in due to CCS and what possible measure could be done to avoid it. FutureGen 2.0 project has not discussed in all the above mentioned studies. FutureGen 2.0 is widely discussed in communication studies i.e. Greenberg et al. 2009, Wade & Greenberg 2009; however the project is hardy discussed in uncertainties management and sustainability studies. Therefore this study is first of its kind to analyse three major uncertainties in FutureGen 2.0 and evaluate sustainability implication of CCS.

This study follows as: Chapter 2 is analytical framework, based on Markusson et al. 2012 Model of uncertainties to analyse the three major uncertainties in FutureGen project. The chapter explains the model with its advantage and its disadvantage and how it is applied to study.

Further the chapter include how to evaluate FutureGen 2.0 through sustainability perspective. Chapter 3- Methodology provides the detail account of the material i.e. documents used for this study, what kind of documents and why I selected, and how I accessed these documents? The document analysis used as method is explained with its advantages and disadvantage and detail account is given about analysing the empirics through document analysis method. Chapter 4 is the discussion and Result achieved through analysis. The chapter deals each uncertainty individually. Chapter 5 include conclusion of the study and its benefits.

Chapter 2: Analytical Framework

2.1 Markusson et al.'s Model of Uncertainties

This section of the study deals with the Theoretical Framework developed by Markusson et al. (2012) for analysing the uncertainties of CCS innovation. Markusson et al. (2012) identified seven key uncertainties and provide assessment procedure how to analyse them. The inter-linkages between the uncertainties are pointed out with specific indicators for each uncertainty. The interlinkages between uncertainties give an insight how one uncertainty could affect the others and via versa. This framework is helpful for policy makers, CCS developers and all stakeholders in managing uncertainties by minimizing the risk of failure while anticipating CCS development and deployment (Markusson, Kern & Watson 2011; Markusson et al. 2012).

The framework was formulated by broad literature review of social science and innovation literatures by interdisciplinary research team and steering group. The framework was refined by interviewing various actors-assessing contemporary technologies in practice, and by reviewing TA document. Through consultation with the stakeholders, the interdisciplinary research team finalize the definition and delimitation of the seven key uncertainties for CCS innovation. These uncertainties are variety of pathways, safe storage, scaling up and speed of development and deployment, integration of CCS systems, economic and financial viability, policy, political and regulatory uncertainty and public acceptance (Markusson et al. 2012).

Based on the significant barriers to commercialization of CCS and relevancy to FutureGen 2.0 project as mentioned in section 1.6: Study limitation; only three major uncertainties are taken in to consideration:

1. Financial and economic uncertainties
2. Policy and regulatory uncertainties
3. Public acceptance uncertainties

Uncertainties in Financial and economic viability are vital to understand Project feasibility. Economic viability could make sure whether to invest in CCS technology or not. A CCS technology might become economical viable if it has high benefit than its cost. However I argue that economic viability does not ensure increase in financial capability due to other characteristics of CCS which might be less attractive than alternatives i.e. social, political, technical etc. This argument is proved valid by interlinkages Markusson et al. (2012) model of uncertainties, further discussed in section 2.2.

An important factor that triggers the economic and financial uncertainties and makes financial viability insecure is the cost estimates of CCS technology. As mentioned by Markusson et al. (2012) that the over optimism about low cost also known as appraisal optimism due to gaining policy support and incentives could make the technology less important. Similarly Hansson & Bryngelsson (2009) described that most of the cost estimates are uncertainty due to lack of various variables. Another important factor in cost estimates that increase the complexity in economic and financial uncertainty is the variation in mechanism and terminology of cost estimation (Rubin 2012). Markusson et al. (2012) mentioned that financial and economic uncertainty is caused by various form of risks i.e. electricity price risks, fuel price risks, operational risk and volume risks etc however they are manageable and could be mitigated with potential policy measures that are needed to be taken. Therefore economic and financial uncertainties are dependent on policy decisions on many grounds i.e. Carbon prices, inclusion of CCS in various schemes e.g. US CSFP, CDM, EU ETS, liability rules, future global climate agreement etc, to be managed (Markusson, Kern & Watson 2011; Markusson et al. 2012)

Policy support and Political issues also affect the CCS development to great extent as comprehensive policy and political choices are needed for CCS commercialization. The factors which affect and trigger policy and political uncertainties are CCS obligations, emissions standards, feed-in tariffs, investments support, assured CO_2 price and low carbon portfolio standards etc. CCS faces severe criticism due to technology has not been proven in climate mitigation portfolio (Markusson et al. 2012). Shackley & Evar (2012) mentioned that the major set-back to CCS is the uncertain status of CCS in climate policy mix.

This is due to carbon lock-in and assumption that CCS would be used to extend fossil fuel regime – a diversion from renewable and energy efficiency towards expanding coal use. The uncertainties regarding liabilities of storage facilities, property rights, trans-boundary issues, lack of comprehensive and clear regulatory framework, leakage liability, third party access, competition law concerns, property concerns, ownership of pore space, and licensing are main policy and regulatory uncertainties that prevails CCS technology (Markusson, Kern & Watson 2011; Markusson, Ishii & Stephens 2011).

Uncertainties are considered inherent in any claim of future technology however expectations are socially constructed by central actors involved in the development of technology.

Similarly CCS activities, related to technology, are increasing while ideas about its implications, significance and future are being constructed (Hansson 2008; Evar & Shackley 2012). However uncertainties articulated in scientific studies mostly ignored public acceptance aspect of technology.

Public acceptance is considered as least important uncertainty in rapid commercialization of CCS in US (Davies, Uchitel & Ruple 2013), however, a wide range of literature signifies public and social acceptance as an important factor for accelerating CCS development (Wade & Greenberg 2009). Most of the stakeholders i.e. government, industry, environmental NGOs are more or less positive towards CCS however some ENGOs and local community have diverse opinion about CCS. CCS storage sites face comparatively less positive attitude or more like negative, in a sense that public in some areas are more concerned with Not In My Backyard (NIMBY) (Markusson et al. 2012). Besides NIMBY public concerns about putting of renewable energies from vital category list and CCS recoiling during development could engenders public acceptance uncertainties. Public acceptance of CCS could also be negatively affected if the public start mistrust over the stakeholders involved in the CCS development causing delay or termination of the project. Therefore managing public acceptance uncertainties before project commence development is vital for project successful completion.

2.2 INTER-LINKAGES BETWEEN UNCERTAINTIES

Uncertainties in CCS could affect each other due to their interlinkages in a number of ways. Markusson et al., (2012) mentioned that policy and regulatory decisions could affect the economic and financial viability in any direction i.e. either positively or negatively. Comprehensive, strong and credible CCS policy and regulation could gain stakeholder confidence and increase public support and financial capability of investment. On the other hand financial and economic viability is vital for policy and public support and has great impact on policy and regulatory decisions. Similarly, lack of risk management, increase in project cost or change in policy could create public criticism against the project.

However change in policy, creating awareness in the community and predicating transparent economic viability could strengthen public acceptance (Markusson, Kern & Watson 2011; Markusson et al. 2012). Uncertainties in any aspect of FutureGen 2.0 could make the whole project uncertain. Therefore managing uncertainties require a holistic approach to make the project successful.

The Markusson et al., (2012) framework for uncertainties assessment are adapted in this study due to holistic nature of the framework to evaluate and analyse uncertainties with more precision and exactitude. The dynamic natures of the uncertainties are reflected with cautious mechanism of indicators. Moreover, as the uncertainties are linked with each other, some of the indicators for uncertainties are also similar for more than one aspect of uncertainties. FutureGen 2.0 is ongoing project anticipated to start operation in 2017.

The Markusson et al. (2012) framework of uncertainties enables to analyse and assess FutureGen 2.0 project or any other project. The framework is helpful in evaluating CCS technology and managing uncertainties before commencing of any kind of project construction due to the dynamic mechanism of indicator. The key Indicators for the above mentioned uncertainties are given below:

Uncertainty	**Indicator**
Economic and Financial Uncertainties	• Costs estimates and Assessment of Quality of Cost data. • Key financial risk • Role of subsidies, other forms of economic support.
Policy and political Uncertainties	• Role of Subsidies and other form of economic support. • Role of other form of policy support • Extent of political commitment
Public Acceptance Uncertainties	• Level of public awareness/ acceptance of risks. • Specific manifestation of public opposition (or support)

Table 1 Three major Uncertainties with Indicators

This framework is recently developed and rarely applied to any studies. The framework has various anticipated advantages. The framework could help CCS practitioners in managing, adapting and reducing the current uncertainties in CCS technology. This framework could also help to know how technological viability would come through innovation processes. By identifying key uncertainties and providing their indicators this framework facilitates and accelerate CCS development and deployment. Other advantage of this framework is that it supports further research and eventually helps decision making on CCS by both private and public actors (Markusson, Kern & Watson 2011; Markusson et al. 2012).

The main drawback of framework is that it is newly formulated and hardly applied in innovation studies however a wide range of applicability in future TA and innovation studies is anticipated. The framework is said to have limited ambition by analysing only seven key aspects of CCS technology indicating a standoff to unknown uncertainties in futures development of technology (Markusson, Kern & Watson 2011; Markusson et al. 2012).

This framework could help to analyse the major uncertainties and evaluate the overall FutureGen project from sustainability perspective. This study could help to identify loopholes that cause uncertainties, strategies to manage these uncertainties, and provide guidance for CCS projects in future. The figure 1 shows concerned uncertainties with interlinkages between them. The figure is extracted from Markusson et al. (2012) uncertainties framework model.

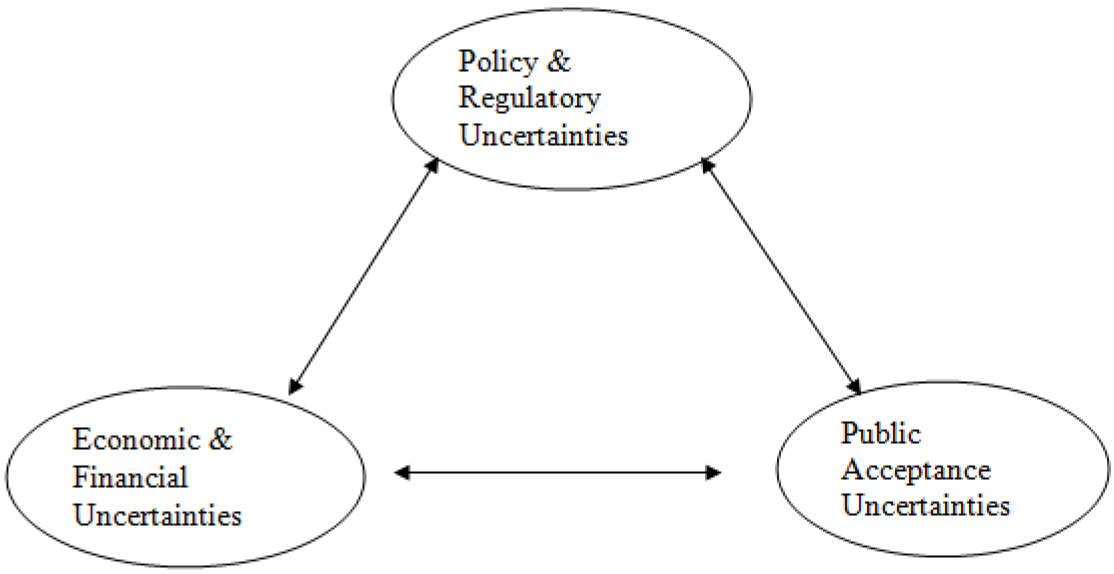

Figure 1 Interlinakges between three concerned major uncertainties (Figure is based on Markusson et al., 2012 model of uncertainties)

2.3 Sustainability Implication of CCS

In United State the sustainability concept can be traced back to Silent Spring published in 1962 and the more especially to National Environmental Policy Act (NEPA) of 1969. NEPA, established goals in 1969, to achieve human existence in harmony with environment besides meeting social, economic and other basic necessities. The NEPA goal become a foundation stone for formation of Environmental Protection Agency (Lewis 1985; The Environmental Forum 2011; U.S. EPA 2014) United Nation Conference in Sweden, where the basic principles of sustainability were established (U.S EPA 2014; The Environmental Forum 2011). Sustainability is based on the concept of maintaining the balance under which human and nature can exist in productive harmony. The basic goal of sustainability is to achieve social wellbeing, economic viability and environmental protection – today and for generations to come (U.S. EPA, 2014; The Environment Forum 2011).Sustainability has three main dimensions or pillars i.e. social, economic and environment (Fiksel et al. 2014; U.S. EPA 2014). Therefore the sustainability implication of CCS is assessed by looking at these three pillars of sustainability. The results achieved from the analysis of the three major uncertainties are evaluated based on three pillar of sustainability and looking at the advantages and disadvantages of overall FutureGen 2.0 project.

Chapter: 3 Methodology

3.1 Material/ Documents used

This thesis is based on desk research and can be termed as Archival Research. Linköping University (LiU) library and data bases are used as primary source. FutureGen 2.0 is a large commercial scale project with numerous corporations and other stakeholders working along with U.S. DOE. Therefore documents from three major sources are used to analyse three major uncertainties that prevail in FutureGen project. The three major sources are:

- Mass media,
- Scientific studies and
- Governmental and organization reports

The three major sources are utilized to have comprehensive and rich empirics. The reasons for selecting mass media as a major source of empirics is that public knowledge and policy issues of emerging technologies are largely dependent on media framing (Zaller 1992). In this study however our analytical focus is not media framing but rather I took mass media as core data besides scientific articles and governmental and organizational publications. Social Scientists advocate that media has profound effect on policy makers and public perceptions about CCS technology (Hansson & Bryngelsson 2009; Zaller 1992).

Numerous studies of CCS took mass media for their empirical basis however these studies apply quantitative content analysis methodologies to represent pros and cons of CCS (Van Alphen et al. 2007; Asayama & Ishii 2013). Stephens (2006, p. 10) emphasized on media analysis of the growing attention to CCS by various influencing actors with great interest in climate change. Hansson & Bryngelsson (2009) mentioned that dominant mass media coverage create public debate awareness that would facilitate decision making processes.

It is important to note that media not only represent news and provide a platform for general societal debates but also contribute in implementation of policies and shaping political agenda (Gamson & Modigliani 1989; Buhr & Hansson 2011). Beside the importance of mass media for data collection, FutureGen 2.0 is also highly debated in mass media. Therefore, Mass media could provide not only information but also give an insight about the concerned uncertainties in the FutureGen project and various stakeholders involved in the project.

Scientific studies provide basic knowledge about CCS technology, technological innovation, uncertainties management techniques and would help in evaluating sustainable implication of CCS technology system. It contains reason behind the technological innovation and CCS development. Scientific articles also give knowledge about risk management of an emerging technology. The results of scientific studies are verified, referenced and reviewed. Then the result of the study is argued and counter argued providing wide range of perception about the CCS. Therefore scientific studies are preliminary important for analysing the major uncertainties in FutureGen 2.0 project and evaluating the overall project from sustainability implication of CCS.

The reason for selecting government and organization report is that FutureGen 2.0 project is combine effort between U.S. DOE and numerous corporations or alliance. And information related to the project development and the members of Alliance is available on the organization and governmental web pages. Therefore empirics from the official documents and organizational reports are vital to get insight about the project progress and how the uncertainties were managed. FutureGen 2.0 project is supported by DOE with aim to become a leader in CCS technology. Therefore governmental reports could provide detail account about efforts made towards sustainability of CCS technology or sustainable innovation.

Further empirics from such a wide range sources would provide balance representation of the project uncertainties and insight about the stakeholders' concerns. Therefore, empirics from mass media, governmental and organizational reports and scientific studies would be helpful in understanding and analysing the concerned major uncertainties in FutureGen Project.

3.2 Data Collection

The data was collected from three major sources by adapting individual approach toward each source. The data collection approach comprises of three steps i.e. document searching/finding access to source and identification. The Linkoping university library databases and Google search engine were utilized in retrieving the documents. In case of unavailability, documents and articles were requested from other universities with in Sweden through inter-university library system. The data collection approach is based on Caulley (1983) method of document searching/findings, accession and identification. All the documents were selected based on relevance to study, complete document, published within the duration of FutureGen project. The intention of the author, document intended to whom, confidential source and author reputation. Based on the Caulley (1983) study following procedure for data collection is used:

Mass Media:

Searching: Google search engine was used for searching news article related to FutureGen project. The search comprised of the following terminologies: 'Uncertainties in CCS' OR

‘Uncertainties in FutureGen project’ OR ‘FutureGen 2.0 project’ OR “Barriers to commercial scale CCS projects’ OR ‘FutureGen Abandonment AND Resurrection’ OR ‘Government support and Public support for FutureGen 2.0’ OR ‘Financial issue of FutureGen 2.0’ OR ‘Sustainability of FutureGen 2.0 project’ OR ‘Sustainability of CCS’ ‘CCS, and Sustainability implication of CCS’. Further news articles were searched related to FutureGen project in the main and renowned daily newspaper in US and State of Illinois to achieve more accurate and specific data.

Accession and identification: News articles from mass media were accessed and identified simultaneously. For some newspaper subscription was made to access the news articles i.e. New York Times, Washington Post. Some newspaper search generated personnel diaries and blog therefore are included in Newspapers articles. Those articles related to FutureGen project; economic, financial, regulatory, political and social aspect of FutureGen project; FutureGen project abandoned and resurrection, uncertainties in CCS and sustainability implication of CCS were selected. These news articles were identified by superficial reading and looking of answers concerning the research questions. A large number of articles were excluded because they were either lack detail information or were identical articles in different news papers. After excluding these articles the remaining set comprised 115 articles, covering a time period from 2003 till October 2013. More than thirty news articles are given in reference list based on their relevance to the major uncertainties FutureGen 2.0 and looking at the article scope through process of skimming.

Scientific Studies:

Searching: Scientific works is published in numerous scientific journals, conferences and books therefore a single term i.e. scientific studies is used for material taken from these sources. The linköping University library data bases were used for searching scientific studies i.e. Scopus, PubMed, Academic Search Premier and Business Search Premier. The search comprises of ‘United State first commercial scale CCS’ OR ‘FutureGen’ OR ‘Carbon Capture and Storage in United State’ OR ‘FutureGen 2.0’ OR ‘Carbon Capture and Storage first commercial project-FutureGen’ OR ‘Uncertainties in CCS’ OR ‘Uncertainties in carbon capture and storage’ OR ‘Economic and Financial viability of FutureGen project’ OR ‘Economic and Financial uncertainties in CCS’ OR ‘Political and Regulatory aspect of FutureGen project’ OR ‘Policy and Regulatory uncertainties in CCS’ OR ‘Public resistance to FutureGen’ OR ‘Risk associated with CCS’ OR ‘Sustainability Implication of CCS’ and Social and Environmental impact of FutureGen project’.

Accession: The Linköping University library facility is granted to all students and student can access to data bases online any time. In case of unavailability scientific articles were requested from other university data bases with in Sweden. A few articles were requested from the supervisor. Books related to CCS and to research methodologies were also issued from library.

Identification: Scientific articles related to uncertainties in CCS, FutureGen project, and three aspects of CCS were primary identified. Further articles related to risks associated with CCS, sustainability implication of CCS and barriers to commercialization were further selected. Scientific articles were identified by first looking at the topic of the articles and then problem formulation and aim of that study. Numerous scientific articles were abundant due to the aim of article were either irrelevant to study in hand or they contain general information about CCS that was already acquired from other articles. In books only those chapter which are related to policy and regulatory aspects; economic and financial concerns and public acceptance were identified by reading the summary of those chapters. While the title of chapters also give information about the theme of those chapters. All scientific work used for this study is provided in reference list.

Governmental and Organizational Reports:

Searching: As mentioned earlier FutureGen 2.0 is combine effort between US DOE and FutureGen 2.0 Alliance. Therefore some reports come across while searching for scientific studies. Useful information about government and private organizations working on CCS was achieved while collecting data from Mass Media source. Therefore reports and proceeding were searched on governmental and private CCS organizational official websites. The official website has its data base containing track records of reports, proceeding and progress made either annually or on monthly bases. Therefore work related specifically to FutureGen project and generally to three concerned aspects of CCS technology were search in database records from 2003 to 2013. Further public and private organizations were searched on Library digital data bases and through Goole search engine. The terms used were private firms working on CCS, government organization working on CCS, Private and public firm working on Carbon capture and storage, public and private stakeholders involve in FutureGen 2.0 project, and organization working on CCS. After identifying websites of various public and private organizations, I start searching for as almost all organizations have open access to their databases.

Accession and Identification: Reports and proceeding are widely available on the organizational and governmental official websites. Documents related to FutureGen 2.0 project were obtained both from Federal Government of U.S i.e. US-EPA, U.S. DOE and The State of Illinois-U.S and Organization working on CCS For example zeroCO2, Global CCS institute, and MIT-Project database websites. All the reports used for this study are provided in reference list. Reports related to FutureGen project, CCS technology system and risk management of CCS were selected. Some reports are annual publications of organizations, providing detail account about the progress made in CCS technology. Therefore development related to three major aspects i.e. economic & financial viability, policy & regulatory support and public awareness about CCS were identified for analysis. Further the proceeding of FutureGen project related to public awareness and site selection process were also retrieved from the websites.

Authenticity & Credibility of the Documents:

The data was retrieved based on the authenticity, credibility and accuracy. The credible documents were separated from incredible by looking at the authors, source of the document, references and independent corroboration (Caulley 1983). The empirics are collected from the most authentic newspapers, scientific journals, organization databases with high reputation and credibility. The documents for analysis were selected based on the content of the documents that were in accordance with conceptual framework of the study and those which are relevant to the research problem and study aim. All the documents selected have original sources and contain information about the author and publishers.

3.3 DATA ANALYSIS

A large number of disciplines used Document analysis i.e. Sociology, psychology, education, business, journalism, art, and political science etc. (Wharton 2006; Bowen 2009; Merriam 1988). Documents in document analysis include books, background papers, journals, diaries and blogs, newspapers and press release, organizational and institutional reports. Brochures, maps and charts were studied for understanding project locations and surrounding area. Document analysis is widely applicable to organization, programs, case studies and other intense studies (Wharton 2006; Bowen 2009; Atkinson & Coffey 1997).

After preliminary understanding of the FutureGen 2.0 project status, motivation and future anticipations. Document analysis (DA) method is used to extract information, gain understanding and draw out meaning for empirical knowledge. Document analysis is defined as ‘The document analysis is a systematic procedure for reviewing or evaluating both printed and electronic material’ (Bowen 2009, pp.27).

The news articles, scientific studies and governmental and organization reports were analysed in sequence wise. The News Articles was taken as starting point of analysis followed by scientific studies and governmental and organization reports. Among 115 news papers articles 40 news articles were analysed and are included in reference list beside all scientific studies and governmental and organization report used for this study. In the news articles 20 articles represents economic & financial viability and policy & regulatory aspects of FutureGen project, 10 articles each for each aspects. Public acceptance and risk associated with FutureGen project consist of 10 articles. Further analyses of 10 article were also conducted that contained commentary on uncertainties in CCS technology with focus on FutureGen project, methods of carbon capture and implication of CCS. These articles which are analysed are from most authentic and credible news papers and have similar data with more detail information than the remaining 70 news articles.

The number of document analysed from scientific studies sources are 55 including 10 scientific articles discussing economic and financial viability of CCS. Similarly 10 articles deal with policy and regulatory issues of CCS. 10 number of articles deals with environmental, health and safety issue of CCS technology. While six articles provide deal account about communication risks, public acceptance and multi level approach to create CCS awareness and achieve various stakeholders’ confidence over CCS technology. There is wide range of scientific studies related to CCS technology. To gain understanding about the development of CCS 6 scientific articles related to innovation were also analysed. From scientific studies 13 article are those which analyses provided us over all understanding of CCS technology while discussing uncertainties and barriers that hinders CCS commercialization. The scientific studies analyses incurs the potential impacts of CCS development and give understanding about the sustainability implication of CCS technology in long term.

Similarly 20 governmental and organizational reports are included in analysis. Most of the reports contain empirics about policy, regulatory, economic and financial and storage aspects of CCS. Various risks and uncertainties associated with CCS and barriers to CCS in a single report. About 7 reports deals with environmental and social implications of CCS; 5 reports were related to policy and regulatory aspects, similarly 5 reports related to economic and financial aspects of CCS while 3 reports deal with public acceptance are analysed. The information about world wide CCS projects is taken from MIT and ZEROCO_2.NO data bases.

While basic information about FutureGen 2.0 project is taken from FutureGen 2.0 alliance web page.

In this research study most of the empirics obtained from scientific articles are mostly reflected in various CCS organization web pages and several news articles. News articles identified the major uncertainties in FutureGen project and progressed made in development of FutureGen 2.0. The scientific studies were helpful in understanding the Sustainability of CCS beside barriers to commercialization of CCS. The studies also provide knowledge about sustainability implication of CCS. The governmental and organization reports provide an insight how the uncertainties were managed in case of FutureGen 2.0 project and what efforts are going on toward sustainability of CCS technology.

Advantages of DA methodology:

Documents are termed as 'social facts' (Atkinson and Coffey 1997) as Love (2003) pointed out that "*Documents are part of the fabric of our world*" (pp.83). Document analysis has many advantages. The DA was helpful in retrieving a large number of documents from three major sources to fulfill this study aim as the percentage of document availability is high in DA methodology (Merriam 1988; Bowen 2009). Bowen (2009) suggested that DA is favored in case there is knowledge gap or new data is not feasible. As mentioned in Section 1.5: study motivation that there is no study related to major uncertainties prevailing in FutureGen 2.0 therefore DA methodology has the advantage to fill that knowledge gap. The researchers believe that documents are best tool to know the legislative intent and provide evidence for policy direction (Caulley 1983; Merriam 1988; Bowen 2009). I argue that DA would be helpful in understanding numerous policies affects on major uncertainties in FutureGen project. Further DA analysis is efficient research methodology as it is less time consuming and less costly (Caulley 1983; Bowen 2009). Another advantage of DA methodology is that it could evaluate long time-frame projects or programs (Merriam 1988; Bowen 2009). FutureGen project has been initiated since 2003 therefore many events related to the project could be assessed by document analysis. The long time-frame and events covered in documents are with exact name and references ensuring document analysis as precise and accurate research methodology.

Limitations of DA:

In document analysis there are also certain limitations. The percentage of availability is high however mostly it provides insufficient details, i.e. documents are argued to be created for a purpose of a particular requirement, therefore conveys only meaning and not covering the whole social reality (Atkinson & Coffey 1997). Therefore to overcome the insufficiency in documents two other sources for documents i.e. scientific study and governmental & organizational reports are selected. The documents are questions to be aligned with the agenda of organization's policies against the alternative that documents reflect social reality (Bowen 2009). However the empirics obtained from diverse sources also fulfill the purpose of neutrality rather following any kind of organizational agenda.

Why Document Analysis:

The document analysis is used here because it aims to study naturally occurring language contrary to the text obtained from 'artificial context' i.e. formal interviews. Purists argue that In-depth interview and focus groups are not ideal data collection method due to the artificial environment and group dynamics. That is why conversation between individuals within group and interview or focus group is not preferred (Bowen 2009). Document analysis has many functions as a research methodology which is significant for this study. For Example

- DA provides historical insight to understand historical roots (Wharton 2006; Bowen 2009) so could help us in understanding FutureGen 2.0 in historical context and identifying how concerned uncertainties emerged.
- DA suggests further questions for research that need to be asked and answered so identifying gap in existing knowledge and encourage further research that could enhance our knowledge (Bowen 2009).
- It could be used to verify findings and confirm results of the study for credibility; in case of contradiction further investigation is encouraged (Wharton 2006; Bowen 2009).
- DA could identify changes over time and could trace the development over specific time frame in a project or program (Bowen 2009). In case of FutureGen 2.0 DA is the most significant method to trace the project development as the project date of operation has been delayed few times as well as the project design has also changed. Further it could help to know how uncertainties were managed.

3.4 Analysis of Empirics/Data

The empirics are analysed qualitatively. All the documents are collected from the three major sources containing; complete text material, authorship and publication agency information. The documents were acquired to analyse the three major uncertainties in FutureGen project and understanding about sustainability implication of CCS was achieved by tracing project progress towards FutureGen 2.0. The nature of text with in document range from formal official language to scientific therefore analytical approach is both interpretative and thematic. This approach was used first to news articles and then sequence wise to scientific studies and governmental and organizational report.

In the first step the articles were sorted, organized and processed before analyses. The sorting was based on the characteristic of data and aim of the study as suggested by Berg (2009) & Caulley (1983) to achieve document´s authenticity and credibility; And to recognize that documents are produced by authors with certified publishers or authorized organizations/institutions. The documents were arranged in ascending order from 2003 till 2013. After sorting each article was skimmed and superficially examined. The unit of analysis was an individual article. The nature, substance and context of document were skimmed by looking at FutureGen project major aspects i.e. cost, policy support, risk, site and technology in each article. The skimmed documents were explored to reason why FutureGen was abandoned and then resurrected, which leads us to gain insight about uncertainties.

After superficial examination, all the news articles were read again as second step of our analysis. As text within each article was different and varying i.e. some text was related to economic and financial viability of FutureGen 2.0 while other related to policy and regulatory aspects. Similarly some text informed us about the risk associated with CCS while in other articles text gave an idea about sustainability implication. Therefore a coding template was developed apriori during the superficial examination stage taking aim of study, research questions and analytical framework in consideration. The indicators developed for evaluating uncertainties by Markusson et al. 2012 are used for identifying uncertainties in document and performing coding. The coding template was used first for News articles then to scientific studies and governmental and organizational reports. The four broad categories formed code template with indicators and description as follow:

Code Name	Indicators/ Patterns	Description/Concept	Year
Type of uncertainty	Economic & financial, Policy & regulatory OR Public acceptance	Three major barriers to CCS commercialization in US and fundamental uncertainties	2003 – 2013
Causes/emergence of Uncertainty	Lack of policy and economic support, financial risk, lack of regulatory framework and liabilities of storage.	Surfacing of math error, change of policy toward technology and storage site increase cost.	2003 – 2013
Managing Uncertainty	Economic and policy support, risk management, political commitment, public awareness and long term liability management.	US ARRA 1990, oxy fuel combustion, EPA UIC well VI regulation.	2003 – 2013
Effect on project and CCS technology	Advantageous or Disadvantageous	Whether FutueGen 2.0 would lead to carbon lock-in, or it would be successful climate mitigation technology	2006 – 2013

Table 2 Coding templates to generate themes for analysis

In the Second step each article was thoroughly read for confirmation of uncertainties surfaced in first step of analysis. This step also helped the accuracy of coding template. In thoroughly reading of text an individual article was selected as unit to observe moments related to major uncertainties and then perform coding. In each article I paid attention to data characteristic, metaphors, terminologies and linguistic choice of words to perform coding before emerging themes become categories for analysis (Fereday & Muir-Cochrane 2006 & Berg, B., 2009).

Coding process involves recognizing points in text that contain qualitative richness related to major uncertainties and encoding them before the process of interpretation (Boyatzis 1998). For Example in any article emergence of cost increase was the recognizing point for economic and financial uncertainty. Similarly changes in project design provide recognition about policy uncertainties. The text which have recognition points were selected for analyses. Usually either before or after the recognition point for uncertainties in an article rational were discussed. The text of those reasons and arguments is also included in analyses.

The reliability of coding template was determined by applying the code to one scientific article and one report before coding process to whole documents of these two sources. The process was iterative and thoroughly reading was repeated before complete coding was performed. At the end of this step of analysis I achieved following:

1. Three set of coding all documents from three sources.
2. A refined empirical sample

The third step contains the theme recognition and making categories. Themes are generally regarded as patterns in the information that describe and organize the possible observation and interpret aspect of phenomena (Boyatiz, 1998). Encoding the rich material in a document organized the empirics as refined empirical sample to identify and develop theme from them. The themes were discovered by connecting the codes that lead us to pattern recognition in the refined empirical sample by making categories. Table 3: Illustrate the process of connecting the codes and discovering of themes across the three major sources of data. The indicators list show the concern theme indicators while the description list shows the inter linkages between the themes that counter effect each other.

Identified Themes	Indicators	Description/Inter-linkages	Connecting Code
Financial & Economic	Financial Risk, Economic support and Technological variance effect of cost	Lack of economic support and variation in cost estimation methodology, policy toward technology selection affect cost of project	**Type, Emergence, Management and effect of Uncertainties**
Policy & Regulatory	Policy support, political commitments, Subsides and regulatory framework	There is no regulatory framework for CCS. Policy towards technology and storage site selection affect cost and public opinion	
Public Acceptance	Public awareness, specific manifestoes of project opposition, carbon lock-in and long term liability of storage management.	Open competitive process to host the project however lack of regulation governing storage site.	
Sustainability Implicaitons	Advantages and disadvantages of FutureGen 2.0	Looking at energy security, emission reduction, risk management, environment protection and investment diversion	
Time-frame uncertainty	FutureGen termination, risks, public opposition	Lack of policy, financial support and political struggle	

Table 3 Process of connecting codes and discovering themes

Before proceeding to the forth step; the rich text, codes and themes were several times repeated as iteration to ensure all units are consistent and connected before interpretation. The refined empirical sample was used for iterative process to ensure all codes were correctly performed to achieve themes recognition and remained open to emergence new theme (Fereday & Muir-Cochrane 2006; Merriam 1988). A new theme emerged as whether FutureGen would be completed at give time-frame? I term this theme as Time-frame uncertainty (see Table 3).

The following theme achieved is discussed and analyzed in the next chapter.

1. Uncertainties in financial and economic aspects,
2. Uncertainties in Policy and regulations, and
3. Uncertainties in Public acceptance,
4. Uncertainty in Time frame.
5. Sustainability implication of CCS.

The forth step of analysis is based on gaining elicit meaning and develop empirical knowledge instead of our own interpretation (Corbin & Strauss 2008). Corbin & Strauss (2008) mentioned the own interpretation of empirics as researcher bias. The iterative process helped us to gain empirical knowledge instead of our interpretation (Fereday & Muir-Cochrane 2006; Merriam 1988). However to gain further elicit understanding I assigned succinct phrases and design question to describe the meanings of theme and unfold its basic structure.

The concept and structure of every theme were identified by looking at; what increase the cost of the project and why? What kind of technology is used in the project? How is supporting the project and how is against? What are Alternative perspectives? What are the causes of Termination? And by using succinct phrases like: Feelings and Attachment of local people; Reason to initiate FutureGen project; Financial, legal and Policy support; Nature of uncertainties (political, social, technical), Causes of these uncertainties; Steps taken to overcome these uncertainties. The results obtained for each theme were noted down in the table. The stages of development of FutureGen 2.0 from FutureGen project is given in the left column to track the themes while the indicators on the rows shows how the uncertainties emerged and what steps were taken to manage the them in given stage of development.

The results were note done in tabulation form as follows:

Stages of development	Uncertainties Indicators		
	A	B	C
FutureGen Project			
FutureGen Termination			
Transition Stage			
FutureGen 2.0			

Table 4 Uncertainties prevailing in major aspects of FutureGen Project

3.5 Strategy to Resolve Biased Data

The data collected from internet based search is question to bias as mentioned by Berg (2009). One must be careful about the legitimacy of material taken from the web and consider the source of all internet material before depending on it. The data from Google search engine in most cases contains Wikipedia, which is completely avoided due to lack of authenticity of the source. Berg (2009) mentioned that information on Wikipedia is mixed and inaccurate.

News Articles were retrieved from the official websites of the relevant Newspapers. Further for every websites the URL (Uniform Resource Locator) is checked whether website is authentic or invalid. The domains of all websites are scrutinized.

Data from the website with the domain '.gov' ; '.com' ; '.org' ; '.edu' etc. are used while Net files with domain '.net' are avoided. It is important to mention that for analysing media article great care was taken, as the contemporary media reporting has multifaceted role i.e. News articles consists of statements from interviews and references to scientific paper, press release, official documents, other article etc. Therefore original source of the statements and other voices were frequently checked and were referred to avoid misunderstanding.

All those websites are avoided that are for some reasons or other not frequently updated and contains outdated data and files. For example some websites though contains some information about FutureGen activities however not updated and were expired. So data is also evaluated on the basis of currency and how regularly the website is updated.

Chapter 4: Results and Discussion

4.1 ECONOMIC AND FINANCIAL UNCERTAINTIES

Economic and financial uncertainties theme unfolds many sub-uncertainties. Almost all documents translate the uncertainty about the project cost and lack of policy support, to mend the increasing cost, lead the FutureGen termination (Folger 2012; Goldston 2008; Pollak et al. 2011; Petroleum Economist; Sylvan 2012).

FutureGen project was initiated by Department of Energy (DOE), United States (US) in 2003 as an effort to mitigate climate change and exploit coal resources. About $950 million cost was estimated to produce 275 MW with near zero CO_2 emissions through Integrated Gasification Combined Cycle (IGCC) technology (Greenberg & Hund 2010; Hallerman 2013a; Stephens, Markusson & Ishii, A 2011). FutureGen Alliance selected at Mattoon III, East Central Illinois as a host site among four suitable sites in December 2007. The Project was intended to be operational in 2012 prior to start of its construction in 2009. However the project was abandoned due to cost overrun. The project remained suspended due to the lack of financial support and Department of Energy's (DOE) interest to resolve financial constrain due to the upcoming 2008 Presidential election (Geman & GREENWIRE 2009; Goldston 2008; Sylvan 2012). The project abandonment unfolds the financial uncertainties that hindered further development.

Cost estimation for new project is considered most intriguing and mostly erroneous and therefore is the primary uncertainty in CCS commercialization (Blyth et al. 2007; Bryngelsson & Hansson 2009; Davies, Uchitel & John 2013). In case of FutureGen project economic and financial uncertainties became obvious when the project's estimated costs rose to $ 1.8 billion, almost double of the initial estimate.

FutureGen was initiated by the DOE as a research project for new technologies and could not be titled as a true demonstration project. Under the agreement the coal and energy industry was obliged to contribute only 20 % of the project costs but later on it rose to 26 % while the rest (74%) was to be provided by the DOE. Among the 76 % DOE share $ 80 million was expected from the international community i.e. foreign governments (Folger 2012; Geman & GREENWIRE 2009).

The DOE pushed the coal companies to pay 50 % of the increases however the coal companies offered to fund their share in debt return; a profit which companies make

eventually by selling electricity (Folger 2012; Geman & GREENWIRE 2009; Goldston 2008;). FutureGen development activities required urgent financial assistance although such an offer seems sensible from coal corporations' point of view.
According to (IEA 2013) hundred commercial CCS project are required to be operational till 2020 to make CCS a significant contributor in global CO_2 remediation. Therefore to achieve technological leadership in CCS FutureGen project was required urgent funding. Ultimately the coal companies' offer was regarded insubstantial and thus was rejected by the DOE and the Secretary of Energy Samuel Bodman terminated the project in January 2008. The rational for coal companies to avoiding urgent funding to manage cost increase could be the investment risk. Blyth et al (2007) mentioned that the decision of investment by companies in power generation project depends on and is subject to strategic, commodity, regulatory, environmental and technical risks.

FutureGen developers and some CCS experts believe that risk management was a significant factor in cost overruns as FutureGen deals with complex technology problems (Folger 2012; Greenberg & Hund 2010; Campbell 2013). Risk management for such large commercial scale project is an important factor to deal beforehand. The FutureGen Alliance was either in haste to complete the project or the uncertainties were overshadowed by the commercial nature of the project in cost estimation. Beside the risk management cost estimation lack accuracy and precision and requires great care and attention (Blyth et al. 2007; Bryngelsson & Hansson 2009). The lack of accuracy in cost estimation of FutureGen project became obvious when Government Accountability Office reported $500 math error by U.S DOE (Herbert & Jackson 2009; Volkmann 2009; Wald 2009).

Cost paradigm of CCS is not only intriguing but also difficult to predict with accuracy. According to Bryngelsson Hansson (2009) and Hansson (2008) costs are dynamic and are affected by new and unexpected problems. That is why dynamic price shifts in cost scenario is considered as a major cause of financial uncertainties in CCS. Furthermore updating data by including too many variables e.g. risk management, in cost scenario increases complexity resulting in low transparency of cost scenario which leads to losing confidence on the cost estimation (Bryngelsson & Hansson 2009; Rubin 2012), While CCS is integration of numerous technologies and is already considered a complex technology matrix (Markusson et al. 2012; Markusson, Kern & Watson 2011). This increase in complexity could be one reason for limited approach towards the risks management. Therefore the DOE's math error is understandable as an inherent uncertainty in cost estimations lead to economic and financial uncertainties.

According to the Government Accountability Office report on FutureGen's cost estimation; the DOE estimated FutureGen cost of $ 950 million was in constant 2004 dollar i.e. the purchasing power of dollar in 2005. The report also mentioned that the decreasing value of dollar in upcoming years due to inflation also contributed to the project as cost increase Volkmann 2009; Wald 2009). Neither FutureGen alliance nor DOE fully focused on resolving the financial and economic uncertainties.

Uncertainties in economic and financial viability of CCS also trigger due to variation in cost estimation mechanism and terminologies. Rubin (2012) discusses that there are different methodologies for cost estimation adapted by renowned public and industrial institutions. These methodological differences result in variation in cost estimation. Besides variations in cost estimation, the terminologies used for cost of emission reduction are also varying. Rubin 2012 mentioned about few terminologies that are mostly used in CCS literature for GHGs emission reduction i.e. cost of CO_2 captured; cost of CO_2 abated/reduced and the increased cost of electricity in calculation metrics.

All these terminologies have same calculating metrics and is defined in same currency unit i.e. dollars per ton CO_2 however they are incomprehensive due to great variations in terminology and methodology. FutureGen project cost estimation was is based on National Energy Technology Laboratory (NETL) of DOE calculation metrics and used the term '*The Cost of CO_2 avoided'*. The common theme of 'Cost of CO_2 avoided' is to compare a plant with CCS to that of without CCS (Rubin, E., 2012). The same calculation matrix is used for FutureGen 2.0 however due to variation with respect to other countries transfer of CCS technology in future and knowledge sharing creates complexity.

FutureGen survived through the American Recovery and Reinvestment Act of 2009 DOE issued $ 1 billion in financial support to the project however the project remain stagnant in transition stage for more than one and half year (Coalage, 2011; Folger 2012; Darling 2010; Merion 2009). Initially DOE approved that it would fund the project with CCS element of the original IGCC technology (Geman & GREENWIRE 2009; Folger 2012). However IGCC as an untested technology was estimated to be too expensive and considered doubtful. Therefore the project was highly criticised (Hughes & Power 2010; Folger 2012; Coburn 2009).

The US Senator Tom Coburn (2009) mentioned that ‘the taxpayers are being forced to finance the largest pork barrel project in our nation’s history with borrowed money’ (Van Noorden 2010; Hughes & Power 2010). Eventually the initial FutureGen project was redesigned with oxy fuel combustion technology and was renamed as FutureGen 2.0. The FutureGen 2.0 Alliance’s aim was retrofitting Meredosia III- an Ameren coal Power Plant also known as Meredosia coal complex and constructing pipeline. The retrofitting of Meredosia coal complex was estimated to cost $ 750 million while constructing of pipeline was estimated to cost $ 550 million. So the net cost of FutureGen 2.0 was elevated to $ 1.3 billion (Coalage 2011; Folger 2012; Hughes & Power 2010; Sector 2009).

In November 2011 an agreement to obtain Meredosia III in southern Illinois, U.S from Ameren Corporation for retrofitting, came to a standstill when Ameren pulled out from the project due to financial constrains. St Louis based utility Ameren had been liable for 20 % of the $ 750 million estimated cost of the retrofitting work. Despite its withdrawal from the deal, Ameren ensured that it would make the plant available for the project. However with uncertainty of who will fund for Ameren’s retrofitting (Coalage, 2011; Ryser 2011; The Associated Press 2011; Wernau 2011).

This created doubt about financial and economic viability of FuturGen 2.0 which surface financial uncertainties of retrofitting Ameren’s portion. Ameren’s withdrawal elevated economic and financial uncertainties in FutureGen 2.0. Markusson, Kern & Watson (2011) mentioned that positive cost benefit ratio of project increase the private investment as the economic and financial viability are vital concerns for investors and policy makers. Such kind of economic and financial uncertainties are exogenous and highly required policy incentives (Blyth et al 2007). Therefore decreases public and stakeholders’ confidence in CCS technology and consequently stakeholders lose hope while local community feel deceived and beguiled.

The FutureGen 2.0 progressed by purchasing segments of Meredosia and went for novation request as de-facto approval of DOE to the alliance for construction and utilization rights over the Ameren power plant. The request has been made possible through the exclusive cooperative agreement of Ameren Corporation with Alliance (Hallerman 2013a). DOE also grants Alliances with the approval to purchase segments of Ameren Old Meredosia Energy Centre for the project’s phase II Capture site.

According to CEO of Alliance, Humphreys, 'We have signed an option to buy segments that are necessary for FutureGen 2.0 project. Generally they include one of the Stream Turbine units, the coal handling infrastructure, the permits, the access to the grid, etc' (Hallerman 2013a). With a strong legal and financial support from DOE FutureGen 2.0 seems to be making impossible into possible. However financial support does not guarantee economic viability of the project (Markusson et al. 2012; Markusson, Kern & Watson 2011).

Concerns over economic viability arose due to the efficiency of plant, as the technical components of plant were old. One Illinois official whose identity is confidential said 'Ever since the Mattoon site fell apart, it has been a joke. You are going to buy an old plant just to prove you can put carbon in the ground, we already know we can do that' (Coalage, 2011). The net revenue was estimated to be $ 3.08 billion by selling electricity and was considered to offset the operational, research and development costs. However, the net revenue could possibly affect the electricity unit rates. In that case an increase in the electricity bills could decrease the purchasing power of electricity utilizes and costumers. Therefore there are obvious economic uncertainties. While the central aim of the FutureGen 2.0 to gain technological understanding, leading to economic gains over time making US the technological leader. Hence such economic uncertainties could be waived off (Hund & Greenberg 2011; Markusson, Kern & Watson., J., 2011; Hughes & Power 2010; Landis 2013b).

At the end of Phase-I work of Front End Engineering Design (Pre-FEED); FutureGen 2.0 faced another cost increase. In November 2012 Alliance declared an increase of about $350 million in addition to those initially estimated occurred which increase the cost of retrofitting the Meredosia coal complex to about $1.1 billion. The total cost increase to $1.65 billion The Alliance mentioned that cost increase has been identified in potential cost savings. (Marshall 2013; The Associated Press 2011; Wernau 2011).

Blyth et al. mentioned that retrofitting coal based CCS power plant has significant effect on the investment so retrofitting the coal power plant on later date could decrease the investment risk. Therefore CCS development is anticipated to become financial and economical viable at the mid of century. However the increase in cost of FutureGen project at various stages ensures that CCS is immature technology for climate mitigation and gaining experience in commercial scale would take time. To manage the increase in cost estimation The Illinois Power Agency in late 2012 gave financial and economic support to FutureGen 2.0 by approving a 20-year procurement plan to obtain all power from the Meredosia coal fired power plant (Hallerman 2013a; Wernau 2011; Landis 2013b). The Illinois Power Agency offer is significant to FutureGen 2.0 because it has not only resolved the financial uncertainty but also given an economic back up to make the project viable.

The FutureGen 2.0 is anticipated to start operating in 2017. The project was started in 2003 and consumed a decade time. The delay in project starts operating could further increase the overall cost and delay the economic benefit. Beside the price of delay, the cost of unidentified and undesirable events which affect human health and environment could also not be ignored. A study carried by Donlan & Trabucchi (2011) estimated the potential public health damages in the three non-selected sites for FutureGen project based on the assumption of 9/11 damages.

Their study shows approximately $ 3.8 million for Tuscola, Illinois in constant 2010 dollar. I termed such unidentified costs along with cost of delay as indirect cost. The indirect cost could be avoided by strong comprehensive pre planning for risk management and regulations. As strong policy and regulation is vital for CCS power plant towards sustainable energy system. The policy and political uncertainties theme is further discussed in section 4.1., of this chapter. Our study results identified that planning beforehand for such events while keeping in mind the indirect cost could be helpful in managing economic and financial uncertainties which could leads to economic viability of the project. The financial and economic uncertainties prevailing in FutureGen project with action taken for its management in form of financial incentives or policy support is given in table 5.

Stages of development	**Uncertainties**	
	Cost	**Financial incentives/support**
FutureGen Project	$ 950 Million	DOE and FutureGen Alliance
FutureGen Termination	Cost overrun	None
Transition Stage	Financial uncertainties surfaced and Ameren withdrawn to support project financially	DOE $1 billion support through ARRA
FutureGen 2.0	$1.65 billion	DOE, Illinois State and FutureGen Alliance

Table 5 Financial and economic uncertainties in FutureGen project

4.2 Policy and political uncertainties

FutureGen was initiated as Agency Action Plan to fulfill NEPA recommendation of clean energy project (Javedan 2013; MIT 2007; NETL 2007). More than half of the U.S electricity comes from coal utilization, while the country has large reserve of coal therefore the coal utilization is expected to increase in coming years. However coal is responsible for enormous CO_2 emissions. About 83% of the total U.S CO_2 emission comes from coal utilization (Raupach et al 2007; Schrag 2007). Among the greenhouse gases (GHG) CO_2 have the highest potential and a major component of climate alteration.

According to IEA scenarios CCS is one key solution for global climate mitigation (IEA 2013; IPCC 2005; Kaarstad, Berger & Svein 2011). IPCC (2005) estimated that the CCS could reduce emission from 15 up to 55 %. These emission reductions of GHGs are estimated to be more expensive in long term if CCS is ignored (IEA, 2013; Kaarstad, Berger & Svein 2011; MIT 2007; Stephens 2006). Although US did not rectify Kyoto Protocol however GHGs emission reduction is indispensable for climate stability and environmental protection (NETL 2007; Pollak et al. 2011; Schrag 2007)

NEPA recommendations with the aim to have clean and secure low cost power plant were not easy to comprehend due independent State level policies in U.S. However the federal energy policies are established by DOE which provide direction for the country energy system at a boarder level and manage research and development funds. Similarly environmental policies and regulations are also mostly established and managed at the federal level by Environmental Protection Agency (Chaudhry et al. 2011; Pollack, M., 2011).

Chaudhry et al (2013) indicate that although energy policy are conducted by DOE however there is great variation among the state related to climate change issue and CCS technology. Therefore gaining policy support for FutureGen project is challenging task. Further coal is considered controversial and environmental concerns of coal become evident when coal was considered as driving force to cause climate change. Numerous ENGO started slogan of 'Coal Free United State' in response to FutureGen project (Chaudhry et al 2013; Noon 2013; Trotta 2013a). To avoid the complexity of various state level policies DOE has adapted the policy of an open competitive site selection process for hosting FutureGen site. In 2005 The FutureGen Alliance and DOE signed Limited Scope Cooperative Agreement. Under the agreement the Alliance has to prepare a conceptual design for proposed FutureGen and start site selection process.

In December, 2007 Mattoon Illinois was selected as site for FutureGen after extensive geological and technical review of the four sites. DOE was assigned to be responsible for initial 4 year of plant operation, testing and research with additional 2 years of monitoring of geologic storage before Alliance would have manage and operate plant. DOE expected FutureGen power plant a 20 year minimum (Maximum 50 years) live time of operation with ability to capture and store about 1.1 million tons of CO_2 per year while producing 275 MW with IGCC technology (NETL 2007; Stephen, J. Markusson, N. & Atsushi, I., 2011).

The FutureGen project was anticipated to start construction in 2009 prior to operate in 2012. However due to cost overrun (as mentioned in the section 4.1) FutureGen came to a standstill and was abandoned. The abandonment of FutureGen surfaced policy uncertainties in CCS and lack of comprehensive regulatory framework of CCS. The policy of site selection is instrumental approach in avoiding contention of independent state level policy and creating public awareness of CCS. However policy and regulatory uncertainties cause to risk the investment of investors. Blyth et al 2007 recommended that policy makers should focus on policy uncertainties and manage the uncertainties to such level to encourage investment behavior of stakeholders.

After the 2008 US presidential election the new administration resurrected FutureGen project. The DOE financially supported the project by announcing one billion dollars financial through American Recovery and Reinvestment Act Funding. The Mattoon, Illinois site was purchased to carry on the development activities (Folger 2012; Geman & GREENWIRE 2009). However the DOE decision to fund the CCS element of the original IGCC project came under severe criticism due to the political motive of having an alternative approach towards the project. Further IGCC was considered expensive, an untested and doubtful technology (Hughes & Power 2010; Folger 2012; Tollefson 2011a; Trager 2009). Therefore the project was redesigned and restructured as FutureGen 2.0.

The revised project design goal was to have initial 60 % carbon-capture with the flexibility to improve to 90 % through Oxy combustion technology instead of IGCC while producing 200 MV instead of 275 MW (Geman & GREENWIRE 2009; Noon 2013; Trotta 2013b). According to Strickland (2010) environmentalists are more interested in coal free electricity and considered 60 % of emission reduction as ineffective strategy to mitigate climate change.

The redesigned and restructured FutureGen got severe criticism from project's opponent in the government, environmental organization and public. The new policies to manage the technical aspects of CO_2 capture, outraged ENGO and public as the old design was intended to capture 90% CO_2. In reaction the community of Mattoon, Illinois disengaged from the project for not getting new power plant. The project got poor environmental reviews and was termed as "YesterGen" by the Clean Air Task Force (Coburn 2009; Darling 2010 Geman &

GREENWIRE 2009; Strickland 2010). The FutureGen 2.0 become doubtful as many environmentalist and NGOs favour United State to become ‘coal free’ while coal should be given less importance in U.S energy mix (Secter 2009; Strickland, E. 2010; Trotta 2013b).

The notion of “coal free” is hard to grasp as America is Coal rich country with more than half power generation comes from coal (Noon 2013; Trotta 2013b; Shrug 2007). While “clean coal” could be embrace with CCS while it still needs to be proven as sustainable option. The sustainability of CCS depends on environmental friendliness, social acceptability and economic viability. According to Corsten et al (2013) considering eutrophication, fresh water consumption, acidification, human toxicity and aquatic ecotoxicity and terrestrial ecotoxicity are important to assess the CCS effect on environment.

The CO_2 leakage from storage well to adjacent aquifers can lead to water contamination. With Overpressure perturbance in the adjacent aquifer are expected beside brine displacement to fresh water and leakage to surface (Careya et al. 2013; Espinoza, Kim & Santamarina 2011; Yoksoulian et al 2013). Leakage above the storage surface can cause health problem and environmental degradation in case of prolong exposure (Corsten et al. 2013; Stephens & Jiusto 2010). Although probability is such risks is low however to ensure future success and CCS sustainability managing these risk are important (Birkholzer & Zhou 2013; Corsten et al 2013; Gerard & Wilson 2009, p. 1098; IEA 2011; Wang 2011).

Korre et al (2011) suggested that strong monitoring programme is essential for health, safety and public acceptance and should be establish from injection period till the project operational period. They argue that leakage may occur even the CO_2 pressure declines when the injection is ceased due to buoyancy forces will push CO_2 upwards. Therefore it is important to analyse FutureGen 2.0 project in relation to above mentioned risks beside major uncertainties.

In 2010 US DOE agreed to support the retrofitted oxyfuel combustion technology at Meredosia, Illinois instead of original IGCC at Mattoon, Illinois after spending 18 months. The decision came after mutual cooperation agreement between FutureGen Alliance and Ameren cooperation under DOE supervision. The Meredosia III of Ameren Corporation was intended to retrofit into oxy combustion for carbon capture facility.While 1000 acres land in northeast Morgan County was estimated to be utilized for project area including 25 acres for the storage facility. According to the CEO of FutureGen Alliance Kenneth Humphrey’s carbon emission would be captured and then transported by underground pipeline 30 miles east to the storage site (Hallerman 2013b; FutureGen Alliance, 2013; Folger 2012).

In pursue to establish a comprehensive liability rules for the FutureGen 2.0, Illinois legislature approved the Clean Coal FutureGen for Illinois Act of 2011. The Act gave the ownership to FutureGen Alliance injection site for CO_2 with interest and liabilities associated with it. The Alliance was granted of private insurance policy till operational phase and additional ten years. The Act empowered to establish a trust fund to supplement their insurance with minimum limit of $25000000. The fund is meant to meet any public loss that should be granted either through insurance company or third party. While on completion of time duration the ownership should be transfer to Illinois government with future environmental benefits with no payment from the State (Attachment C: Testing and Monitoring Plan 2013; Justia US Law, 2013). The act facilitated local and regional community by ensuring liability of ten extra years of post injection phase. The FutureGen 2.0 is the first commercial project to establish policy regarding liabilities of CO_2 leakage. However CO_2 storage remains critical for technical concerns and further study is encourage to see affect on storage and adjacent aquifers.

The US Federal EPA was assigned to establish regulatory activities for CCS concerning storage site and injection well. In 2010 EPA finalized the regulation with requirement of CO_2 storage to governed under Safe Drinking Water Act's Underground Injection Control (UIC) program, including the development of new Class VI of injection wells (U.S. EPA, 2010a; FutureGen Industrial Alliance 2013) and regulation for Reporting under the Greenhouse Gas Reporting Program for facilities that inject CO_2 underground, with or without permanent storage (U.S EPA, 2010b; FutureGen Industrial Alliance 2013).

In august, 2011 EPA proposed to remove the injected CO_2 from the scope of hazardous waste regulation due to the fact that CO_2 to be injected into wells that came under Safe Drinking Water Act. Further EPA considered no risk to human health and environment through management of CO_2 under Safe Drinking Water Act. The UIC VI requires an extensive characterization of the site before construction. U.S EPA illustrates that those materials should be used that are compatible with CO_2 and withstand throughout the life time of storage.

The U.S environmental agency also assigned the responsibility to monitor water quality, well integrity, and CO_2 injection and storage during the life time of the project and post injection concerned care time. Further the EPA entitled financial responsibility requirement to for emergency response (U.S EPA 2010a & 2010b; FutureGen Industrial Alliance 2013).

According to Michael Morris chief executive of American Electric Power "Carbon is political issue, capture and storage is a technical issue and they are as different as night and day." He believes that technical issues can elevate cost (Tollefson 2011a). Same is the case with FutureGen oxy-combustion technology. The uncertainty remain in oxyfuel or oxy-combustion technology as to obtain pure oxygen is expensive and could elevate the net cost of the project. However oxy fuel combustion could not only meet the new Environmental Protection Agency (EPA) regulation of pollutants extraction such as Mercury but could also retrofitted to existed coal power plant to reduce greenhouse gas emissions without switching to natural gas or abandoning the plant.

According to Corsten et al 2013 the capability of oxyfuel is lowest environmental impact and that could offset the surplus energy cost for oxygen extraction. Success of Oxyfuel combustion could make a path for retrofitting the rest of U.S existing coal powered plants (Kemp 2013). However Unruh & Carrillo Hermosilla (2006) CCS development could lead to Carbon lock-in and hinders the development of new technologies. Therefore carbon lock-in limits the sustainability of CCS. The policy and political uncertainties theme is represented in table 6 with policy support to see how uncertainties were managed in case of FutureGen 2.0.

Stages of development	**Policy and political Uncertainties Indicators**	
	Project planning & strategy	**Policy Support**
FutureGen Project	❖ 275 MV through IGCC (90 % CO_2 capture) ❖ Competitive site selection process to avoid independent state level policy	❖ NEPA recommendation for clean coal project with near zero emission ❖ Policy supported by DOE and FutureGen Alliance
FutureGen Termination	Mattoon as project site and Cost overrun	Lack of financial and policy support
Transition Stage	200 MV through oxy combustion (60% till 90 %)	Illinois political struggle for resurrection and ARRA support
FutureGen 2.0	❖ 200 MV through oxy combustion (90 %) ❖ Safe drinking water act ❖ Clean Coal FutureGen for Illinois Act of 2011	❖ DOE, Illinois State and FutureGen Alliance ❖ EPA ❖ Illinois State, US

Table 6 Policy-political & Regulatory uncertainties in FutureGen project

4.3 PUBLIC ACCEPTANCE UNCERTAINTIES

As public acceptance is a social process in which actors influence each other through interactions and not merely person's feeling and apparent risks. Therefore public confidence intensively depends on information circulated by media and various other actors (Greenberg et al 2009; Stephens, Markusson & Atsushi 2011). In case of FutureGen to avoid independent state level policy and to achieve public awareness and confidence a multi stakeholder engagement approach was adopted. The Alliance posted Request for Proposal (RFP) draft including the three criteria i.e. qualifying, scoring and best value on its websites in February, 2006 for public review.

The RFP was developed by 'Siting Team' while the team comprised of Scientists, engineers, consultants to Alliance and members of Technical committee etc. The Technical Committees are advisory experts group, distinguished consultants, member of academia, member of national laboratories and industry representatives (NETL 2007; Hund & Greenberg 2010; Stephens, Markusson & Atsushi 2011). After receiving comments on draft the final draft was posted on Alliance website in March 2006.

Each and every State in US was requested to submit their proposal to host the project. The site selection processes initiate community engagement with ample financial incentive for the community to host power plant with IGCC capturing technology and storage capacity. Each competitor submit their proposal to host the FutureGen project according to prescribe criteria of Alliance (NETL 2007; Wade & Greenberg, 2009; Stephens, Markusson & Atsushi 2011).

The Alliance received 12 proposals from seven states (Stephens, Markusson & Atsushi 2011; Hund & Greenberg 2011). A team of four i.e. two internal DOE expert & two external technical experts and FutureGen alliance semi finalized the following four sites:

- Mattoon, Illinois;
- Tuscola Illinois;
- Jewett, Texas; and
- Odessa, Texas

As a requirement of National NEP act to provide information about project and hear their concerns, the team met with almost two hundred stakeholders for a number of weeks before the public meeting at each semi finalized site. After the submission of Best And Final Offers (BAFOs) on Alliance proposal by the semi-finalists Mattoon, Illinois was selected (NETL 2007; Hund & Greenberg 2011).

Success of every project requires public support and awareness among the local people about the project. Public support always remains decisive in the faith of any project (Greenberg et al

2009; Stephens, Markusson & Atsushi 2009). Stephens, Markusson & Atsushi (2011) and Hund & Greenberg (2011) illustrate that how competitive site selection process lead to public awareness and building confidence among various stakeholders to embrace FutureGen project. However the selection of Mattoon disappointed the community at Texas and considered FutureGen as beguilement (Daily Herald 2008; Goldston 2008; Hund & Greenberg 2011; Merrion 2008).

Merrion (2008) mentioned that when FutureGen was terminated Mattoon community reacted strongly to the decision of FutureGen termination as the decision comes right after the selection of Illinois over Texas as project site; which raised many question about FutureGen. She described that in response to the Energy Secretary Samuel Bodman's decision, Senator Dick Durbin said, 'In 25 years on Capitol Hill, I have never witnessed such a cruel deception, For five years, the Department of Energy has urged our state and others to pursue, at great expense and sacrifice, this critically important energy project. When the City of Mattoon, Illinois was chosen over possible locations in Texas, the Secretary of Energy set out to kill FutureGen'.

According to Goldston (2008) coal industry was successful to strengthen and stir up the local politics to support and resurrect FutureGen project. However there is no source how they manage to get support for FutureGen but there are remarks and statement of certain politician in favour of the project. One such politician is Governor Rod Blagojevich who criticised the former Energy Secretary Samuel Bodman to deceive the people of Illinois who had welcomed the project (Daily Herald 2008; Elizabeth 2008). Coalage (2012) described the statement of Governor Pat Quinn that the state's chief executive is strongly committed to bringing the project to Illinois.

In 2010 DOE resurrected and survived the original FutureGen design and location with immense financial support. However during the process of resurrection the IGCC technology was replaced with the oxyfuel combustion technology on reason that the IGCC is expensive and unproven technology. Further the scope of the project was also reduced 60 % carbon capture with flexibility to increase to 90 % in future producing 200 MW from coal.

The ENGO criticized the FutureGen 2.0 project due to retrofitting Ameren and 60 % carbon capturing while Mattoon community disengaged from the project in response to alternative technology instead of IGCC (Noon 2013; Strickland 2010; Folger 2012; Geman & GREENWIRE 2009; Secter 2009). Therefore FutureGen Alliance finally agreed to produce 200 MW electricity by retrofitting Meredosia III coal power plant; capturing 90% CO_2

through oxy combustion technology (Folger 2012; FutureGen Alliance 2012; Landis 2012 & 2013b; The Associated Press 2010).

It is obvious from discussion that public perception plays a vital role in technology development. The effort of Mattoon community resurrected FutureGen while ENGO efforts compelled the FutureGen Alliance for a 90 % CO_2 capture instead of 60 %. In 2010 Ashland Site at Morgan County was selected for CO_2 storage site. The captured CO_2 at Meredosia coal complex is intended to be transported to Ashland, Morgan County through underground pipeline (Pacheco 2011; FutureGen Alliance 2013c; Marshall 2013; Energy.Gov 2010).

The Transportation by underground pipeline requires digging in a certain path which includes many areas of interest to regional people i.e. farms and agriculture land. Landis (2011) mentioned that some landowners are concerned about underground pipeline considering FutureGen 2.0 project as 'unsafe boondoggle'. He described the farmer's perception about the FutureGen 2.0 project and noted down their comments. One such farmer is Bob Talkemeyer, who he mentioned as

> 'Bob Talkemeyer a local farmer whose Family's farmed the storage site area for more than 100 years and is greatly concerned with safety hazards of carbon storage. B. Talkemeyer mentioned that due to the area's need for economic development the potential hazardous effects are overlooked. He considered that 'the site is State's best farmland and Project initiator come to drill into the middle of God's best earth which soon will become cesspool underground'(Landis 2011).

To keep the trust of the people and to remain the consensus intact FutureGen Alliance's CEO K Humphrey ensured that FutureGen 2.0 would purchase underground storage rights while the landowners would retain rights to topsoil. He estimated a total $325000 a year royalty payment to land used for transportation purposes (Landis 2011).

The royalty payment represents a step to gain public acceptance however it is not obvious in any documents whether such payments could add to the project cost engendering financial uncertainties. Further the royalty payment ignores environmental damage and overlooked human health and safety. A studied conducted by Donlan & Trabucchi (2011) argue that if the cost of the unexpected events i.e. Cost of accidents and risks to human health during construction added to project cost, the overall cost increase.

Managing environmental and health risks at planning stage of project could overcome public acceptance uncertainties without affecting policy and financial aspect of project (Donlan & Trabucchi; Korre et al 2011; Stephens, Markusson & Atsushi 2011). The FutureGen Alliance is willing to address these issues and committed to restore the farm land. At the request of local land owners FutureGen 2.0, Alliance assured that the Service road connecting Beilschmidt Road to the Characterization well, constructed by the Alliance will remain in place (Mann 2012; Pacheco; 2011; Landis 2011).

In response to the storage site some opponents of FutureGen 2.0 at Morgan county has signed more than 500 petitions concerning the public health and safety of the storing CO_2 underground besides overrun project cost. The project opponents consider FutureGen 2.0 as waste of national wealth for small reward to Illinois State compare to financial and public risk (Hughes & Power 2010; Landis 2011). Andy Davenport, a local farmer whose family farm is near the proposed storage site mentioned that such a project would affect not only Ameren Customers and local people but all the people of the state as the FutureGen 2.0 is resurrected at the taxpayers money and expense of electric customer (Landis 2011).

The response of FutureGen alliance is not obvious in documents however Alliance has ensures that about 39 million metric tons of captured CO_2 would be stored 4000 feet deep over 30 years and would environmentally monitored for 50 years ahead (Hallerman 2013; FutureGen Alliance, 2012). Further EPA has developed a regulatory framework known as UIC Well VI for constructing CO_2 storage site. As discussed in section 4.2 of this chapter the regulation illustrate that a comprehensive and strong environmental monitoring of water quality, well integrity and leakage is required for both pre injection and post injection period (U.S EPA 2010a & 2010b; FutureGen Industrial Alliance 2013)

The water quality, well integrity and leakage also depend on the geology of storage site. The storage site at Morgan County is said to have sandstone formation. The upper shale layer is helpful to serve as "Cap" of storage reservoir. The Alliance selected the deep saline formation after in depth review by scientist, technical experts, and DOE officials (Mann 2012; Pacheco 2011; ZEROCO$_2$.NO 2013). However According to Tollefson (2011b) Kurt Zen House a President and founder of C12 Energy criticized Morgan site as defective for large scale storage. He mentioned that Kurt Zen House's Company C12 and its backer support a different site for CO_2. He described Kurt Zen's views as:

> Kurt Zen argue that the FutureGen 2.0 inject the CO_2 into porous sandstone with no dome or other structure to help trap the gas. Further he pointed out that the Alliance strategy of storage site risks legal and financial concerns if the CO2 spreads farther than expected' (Tollefson 2011b).

Daniel Schrag, a geochemist at Harvard University in Cambridge, Massachusetts also argues that besides lacking the structural trap; the sandstone in Morgan County sits at a slight angle and is shallower than that in Fayette County. He emphasize that "in such formation CO_2 are likely to be more mobile and less predictable. And could "poison the well" for CCS if legal problem ensue (Tollefson 2011b). The FutureGen 2.0 Alliance responded to the geological claims about storage site and mentioned that Morgan County is of suitable geologic quality having extensive reservoir capacity for permanent CO_2 storage and nearest transport route to Meredosia coal complex. After the completion of drilling Characterization well in 2011 an extensive geologic testing and engineering studies were conducted.

In July 2012 FutureGen 2.0 Alliance officially announced that Morgan County in Illinois is feasible for CO_2 storage (Mann 2012; Pacheco 2011; DOE, 2012). The Alliance confirmed that the 500 foot thick Mt. Simon Sandstone is a suitable site with potential to store CO_2 and has 460 foot thick Eau Claire formation as a cap rock. The characterization well is now said to be ready for hydrological testing to see the formation response to CO_2. FutureGen Alliance also committed to restore the top layer of farmland besides monitoring the well (Pacheco 2011; Tollefson 2011b).

Morgan site is also preferred for developing visitor centre and research and training facilities near storage site Further the regulation designed by U.S EPA for storage site and underground well ensures liability of long term to manage health, safety and environment. Public uncertainties theme is represented in table 7 describing opposition and policy support and awareness program.

Stages of development	Public acceptance Uncertainties	
	Opposition/ criticism	**Awareness and support/acceptance**
FutureGen Project	Nill	Open competitive process
FutureGen Termination	❖ Texas disappointment over Mattoon selection. ❖ Mattoon reaction to Project termination ❖	❖ Mattoon selection as project site. ❖ Cost overrun
Transition Stage	Some criticism from opposition over DOE financial support	❖ Mattoon community struggle for FutureGen 2.0. ❖ DOE support through ARRA to resurrect the project.
FutureGen 2.0	❖ Mattoon disengagement from project due to oxy combustion tech. ❖ C12 company criticism+ some farmers. ❖ Not confirmed	❖ Retrofitting Meredosia III through oxy combustion. ❖ Morgan county as storage site ❖ Royalty payment to landowner and farmers

Table 7 Public acceptance uncertainties in FutureGen project

4.4 TIMEFRAME UNCERTAINTIES

The timeframe uncertainties is the forth theme of our study. The result and discussion of above uncertainties show that FutureGen started in a hectic manner, lacking policy and financial support; consuming a massive time of decade. After FutureGen has been resurrected as FutureGen 2.0 it took a massive time of 18 months as transition state from FutureGen to FutureGen 2.0, making it critical to be completed till 2012.

Therefore the operational date for FutureGen 2.0 was extended to 2015. The CEO of FutureGen 2.0 Alliance Kenneth Humphrey mentioned in response to time spending that the project will completed on the due time however due to persisting uncertainties and lack of regulatory framework the project commencement time was further delayed till 2017 (Hughes & Power 2010; Folger 2012; Landis 2013b). I argue that the delay in the world's only commercial CCS project could affect the overall CCS development pathway towards climate mitigation goal leading to the timeframe uncertainties in IEA and IPCC targets.

The IPCC (2005) estimated that the long term potential of CCS would be 15% to 55% of cumulative emission reduction by 2100. Similarly IEA estimated that 100 CCS project till

2010 could be significant contribution in climate mitigation. Further the reduction of CO_2 emission required urgent implementation of CCS technology (Kaarstad, Berger & Svein 2011; IEA 2013; Shrug 2007).

According to IEA (2013) 2˚C scenario (2DS) required 14 % cumulative emission reduction between 2015 and 2050. CCS could contribute to one sixth of CO_2 reduction till 2050. Without CCS the overall cost of emission reduction till 2050 would increase by 70 %. While in business as usual scenario the GHG emission would result in global temperature rise to 6 ˚C. Projects like FutureGen 2.0 are the need of day to avoid temperature increase and climate change. Therefore it is vital to take time framework uncertainties in estimating cumulative emission reduction.

The long timeframe in FutureGen 2.0 development decrease the project feasibility as the delay in CCS development further increase the cost of CCS in future (IEA 2013; IPCC 2005; Pollak et al 2011). Further the project is funded under the stimulus bill and FutureGen Alliance must spend its stimulus dollars before 30th September, 2015. In case of failure the unused fund must return to the treasury (Landis 2013b; Folger 2012). Alliance official are optimistic that they can utilize the money within the given time. According to CEO of FutureGen Alliance Humphreys said "We have still got a cushion between now and the ARRA deadline, but time is of the essence, every month matters" (Folger 2012; Hallerman 2013a).
However any kind of delay in FutureGen 2.0 could not only decrease project feasibility but also the IEA estimation of 14 % cumulative emission till 2015 and 2050 seems unrealisable; effecting the overall climate mitigation. Therefore timeframe uncertainties should be taken in consideration avoid exaggerating other uncertainties and increase in cost.
In case of FutureGen 2.0 the achievement of regulatory framework and legislation for developing CCS power plant offset the timeframe uncertainties. FutureGen was initiated at time when there was fragmented legislation governing CCS power plant utilizing fossil fuel and lack of regulation for health, safety and environmental impacts of CO_2 leakage.

It is evident from policy change studies that for any policy change required a lengthy timeframe i.e. in decade (Sabatier & Jenkin 1999; Pollak et al 2007). Therefore time consumed by FutureGen 2.0 could be counted for policy change and establishing regulation governing CCS. The success of FutureGen 2.0 project would make the FutureGen Alliance leader in CCS technology. However it is suggested that timeframe uncertainties should be taken in consideration while initiating new CCS project. Timeframe uncertainties are given in table 8 with its indicator. In below table no. 8 four indicators have been used.

Stages of development	**Time frame Uncertainties**			
	Stating Year	**Operational year/delayed**	**Cost increase**	**Policy change**
FutureGen Project	2003	2012 – But terminated before 2012.	See Table No. 3.	See Table No. 4.
FutureGen Termination	2008	-		
Transition Stage	2008	2009-10		
FutureGen 2.0	2010	2017		

Table 8 Timeframe uncertianties in FutureGen project and over all CCS development

4.5 Interlinkages between Uncertainties:

Uncertainties in one aspect of the FutureGen project affected uncertainties in other aspects and exaggerated the overall effect by delaying the project and increase in cost. Markusson et al., (2012) mentioned that uncertainties in one aspect could affect the overall efforts towards uncertainties in other aspect of technology. In case of overall FutureGen project financial and economic uncertainties were emerged due to lack of policy and public support. For example termination of the FutureGen and redesigning FutureGen 2.0 have surfaced the financial uncertainties in overall project (Daily Herald 2008; Goldston 2008); indicating strong interlinkages between financial and economic uncertainties with policy and political uncertainties and public acceptance uncertainties.

Blyth et al (2007) mentioned that policy uncertainty impact the investment behaviour. The policies and regulatory uncertainties are considered to affect public acceptance uncertainties and financial and economic (Markusson, Kern & Watson 2011; Markusson et al. 2012). The result and discussion of the three major uncertainties show that there is strong linkage between them and one uncertainty reinforced others.

The policy towards redesigning and restructured project not only affected the cost of project but also the public concerns about the project. The project got severe criticism from opponent in the government, environmental organization and community until the project was moved from Mattoon-Illinois to Morgan County-Illinois. The project got poor environmental reviews and was termed as "YesterGen" by the Clean Air Task Force (Coburn 2009; Geman & GREENWIRE 2009; Darling 2010). In same manner project cost increase to $ 1.65 billion, almost double of the initial cost occurred due to political and policy uncertainties in FutureGen project.

Moreover the project spent a massive time of 18 months in state of transition from FutureGen to FutureGen 2.0 due to lack of policy and regulatory framework. Spending such lengthy time in resurrection and bringing project back on track caste doubt in project completion, engendering time frame uncertainties (Hughes & Power 2010; Folger 2012). Delay in project commencement could also be counted for further increase in cost resulting in financial and economic uncertainties when Ameren pulls out from the project. The interlinkage between the major uncertainties is represented in figure 3.

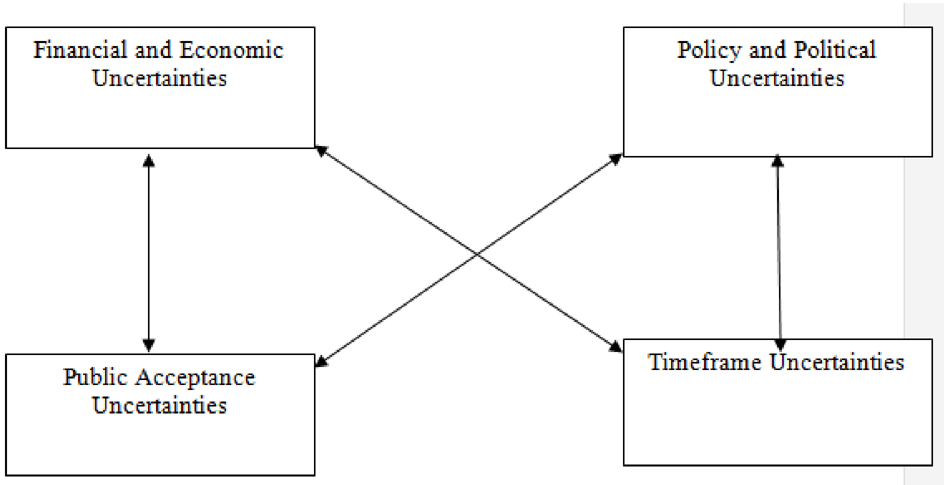

Figure 2 Interlinkages between major uncertainties in FutureGen project.

4.6 Sustainability Implication of CCS

From the above chapter it is clear that FutureGen 2.0 struggle to achieve design policy and regulatory framework for CCS technology. Many concerns related to environmental damage and risks related to CCS storage are managed by policy and financial support. The success of FutureGen 2.0 would enable U.S to sustain the modern life style by utilizing fossil fuel besides making FutureGen Alliance the technological leader in CCS. However the commercialization success of CCS is bonded with sustainability implication. There are numerous sustainability implication however to have understandable representation and in coherence with three pillars of Sustainability these implications are categorize in three sectors. That is:

1. Economic
2. Environmental
3. Social

Economic Implications of CCS:

As mentioned in section 4.1. CCS is costly technological option for climate remediation (Bryngelsson & Hansson 2009; Folger 2012) therefore one important Sustainability implication of CCS is extensive capital cost of installing CCS process equipment. The high capital of CCS is due to the capture cost of CCS (Buhre et al 2005; Kemp 2013; Wall, Stanger & Stanley 2011; Yang et al 2008). In case of FutureGen 2.0 project Oxy combustion capture technology is used (Kemp 2013). The oxy combustion carbon capture technology is considered costly capturing technology because energy input required for an air separation unit (ASU) to supply pure oxygen for systems (Buhre et al 2005; Kemp 2013; Wall, Stanger & Stanley 2011; Yang et al 2008). A typical ASU is calculated to consume about 200 kWh/t CO_2 power inputs which indicate huge cost in term of energy lost (Buhre et al 2005; Kemp 2013; Yang et al 2008; Stangeland 2007). Energy is also required to isolate CO_2 from coal or fossil fuel, this energy is known as parasitic energy, causing reducing energy output and increase in cost of the plant. Due to such drawbacks in CCS, increase in power generation cost is critical concerns for energy policy to manage the transition to clean energy. Therefore carbon tax on CCS based energy consumption in future is considered to make CCS competitive (Blyth et al 2007; Stangeland 2007; Yang et al 2008).

Further thermoelectric power plants consume a large amount of water for cooling purpose during carbon capture and operation processes. It is expected that growing water demand could increase water price, making it difficult for development of power plant involving freshwater sources (Dooley, Kylea and Davies 2013; Tidwell et al 2013). Therefore to avoid water lost during power generation future thermoelectric power generation technologies would prefer dry cooling system which incurs higher costs, lower thermal efficiencies, and lower power output, leading to cumulative increase in the total costs of electricity generation (IEAGHG 2011; NETL 2008, 2011). However, incurred cost is not considered serious threat to the CCS development keeping in mind broad-based climate policy (Davies, Kyle and Edmonds 2013; Kyle et al 2013).

Another important implication of CCS is that huge investment and public and private financial support in CCS will divert resources from renewable energy system and even other clean energy technologies (Stephens and Jiusto 2010). CCS is considered to restrain public RD & D funding and incentive from development of other clean energy technology, which incur carbon lock-in of CCS (further discussed in this section under social implication of CCS).

Environmental Implications of CCS:

The greatest environmental benefit of CCS is the production of clean energy without carbon emission. Carbon emission reduction is greatest and primary concern for climate change remediation. However a single rational of emission reduction could not term CCS as sustainable solution while there are numerous environmental implications and make CCS as a less Sustainable option. For Example CCS could exacerbate other environmental impacts of fossil fuel use including mining, water pollution and water crises, alteration in geology, human and environmental safety and other non-carbon air pollution (Dooley, Kyle & Davies 2013; Stephens & Jiusto 2010; Yoksoulian 2013).

One significant sustainability implication of CCS is the growing water demands for the development of thermoelectric power plants. The emergence of stringent climate policies to reduce GHGs and remediate climate change compels changes in energy system and electricity sector to a large extent. There is uncertainty about the effect of CCS on water however it is assumed that CCS based power plant development could not be extrapolate with current water demand of thermoelectric power plant. While doing so CCS development could lead to competition for water among various water required sector i.e. domestic and agriculture (Fthenakis & Kim2010; Kyle et al 2013). Therefore it is important to include water demand in future development of CCS power plant chain (Dooly, J and Kyle, P and Davies 2013; Tidwell V et al, 2013). Although oxy combustion has limited effect on water and considered water effecient however overall CCS system could have immense effect on water especially in case of amine based capturing technologies (Fthenakis Vasils et al., 2010; Tidwell V et al., 2013).

Further environmental implications of CCS are the risks associated with CO_2 storage reservoir. These risks ranges from leakage of CO_2, ecological degradation, deformation of geology, seismicity, ground water contamination and CO_2 impact on human health, property and environment. Many factors determine the sustainability of CO_2 storage reservoir ranging from Geochemical behavior of CO_2, duration of CO_2 in well to the geomechanical process of injection and geological formation (Espinoza, Kim & Santamarina 2011; Stephens & jiusto 2010; Yoksoulian et al 2013). Geochemical behavior further depends on duration of CO_2 in the reservoir. Geochemical effect include degradation of well, precipitation of potassium feldspar, dissolution of sediments in case of clay minerals, precipitation of sulphur etc. (Espinoza, Kim & Santamarina 2011; Yoksoulian et al 2013). The well resistance to geomechanical damages depends on mechanical properties of wells materials and its strength of bonding (Careya et al. 2013; Espinoza, Kim & Santamarina 2011).

Yoksoulian et al 2013 studied chemical behavior of CO_2 in the Mt. Simon Sandstone and Eau Claire Shale geological formation. The petrographic and geochemical observations of Mt. Simon Sandstone show that clay mineral dissolution may increase capacity for CO_2 by enhancing porosity. In case of Eau Claire Shale some degree of chemical reactivity occurs however the magnitude of this reactivity was difficult to measure while mineral degradation beside color change was observed (Yoksoulian L.E et al 2013). Although Morgan County CO_2 storage site of FutureGen 2.0 project has been marked as suitable and safe geological storage and characterization well has been successfully tested (Bonneville et al 2013); still further study is encouraged to understand the impact of CO_2 of the storage reservoir, surrounding environment and water.

The environmental implications of holistic based CCS system would make way for the utilization of fossil fuel. The risk related to fossil fuel mining, transportation and combustion gases that facilitate acid rain, smog and health hazards would cause broader environmental damages (Clean Air Task Force, 2001; Stephens J and jiusto S 2010).

Social Implications of CCS:

FutureGen 2.0 project adopted multilevel approach of site selection process to create public awareness and gain stakeholders confidence. The FutureGen 2.0 project site selection process could serve to achieve societal acceptance of other CCS project. However due to uncertain nature of CCS and complex integration of technology; CCS could have intriguing societal implication. Moreover it is still early to say whether CCS will be successful in transition to clean energy technology or it will dominate energy market. CCS innovation is argued to have itself primary driver of development of new fossil fuel based power plant especially coal and therefore considered to lead to carbon lock-in (ORNL 2007; Unruh & Carrillo Hermosilla, 2006).

Carbon lock-in restrains alternative innovation to gain market share which delays the technological transition and pose an important social challenge. Further carbon lock-in address changes by technological fixes and make the system efficient (Markusson & Haszeldine 2008; ORNL, 2007; Unruh 2000; Unruh & Carrillo Hermosilla, 2006).

The political and corporate ambition to develop CCS may avoid the challenge of renewable energy and other low carbon energy technologies. Further financial risks associated with technology suggest that CCS will highly dependent on public funding for many years

(Stephens & Jiusto 2010). While large investment would be diverted from other renewable and clean energy technologies. Therefore FutureGen 2.0 project as corporation between U.S DOE and coal companies ensures that the success of project would facilitate CCS to lock-in. However one possible argument is that CCS is viewed as bridging technology that would facilitate to transition of renewable and other low carbon technologies to sustainable energy (Van Alphen, Hekkert & Turkenburg 2010; Vergragt et al 2011). Although the sustainability implication of CCS limits the role of technology, still FutureGen 2.0 remain successful in achieving management of numerous uncertainties and development of regulatory framework to ensure safety of environment, health and property.

This study is an attempt to fill the knowledge gap concerning major uncertainties in FutureGen project and how it progress to FutureGen 2.0 beside looking at sustainability implication of CCS. This study could help in managing uncertainties while initiating new CCS project and could enhance the implementation of CCS deployment. Besides enhancing knowledge about future commercial size CCS projects, this study would also help in CCS awareness among the people.

Chapter: 5 Conclusions

5.1 CONCLUSION

CCS is anticipated to mitigate climate change by reduce carbon emission while utilizing fossil fuel to sustain the modern life style. The interest in CCS is growing although the technology is considered immature. Numerous large scale projects have been initiated around the world however lack of commercial scale project is inherent uncertainty in CCS. To overcome commercial feasibility of CCS and to achieve 15% to 55 % cumulative emission reduction some commercial scale project was initiated however most of them was terminated due to emergence of uncertainties.

The FutureGen 2.0 is only effort to make CCS commercial viable. The FutureGen project was terminated due to uncertainties in 2008 however it was resurrected to fulfill NEPA recommendation to have near zero emission clean coal power plant. Through document analysis three major uncertainties prevailing in FutureGen project were analyzed i.e. Policy & Political, Financial & Economic and Public acceptance uncertainties.

Documents are identified, accessed and selected from three sources i.e. News Articles, Scientific Studies and Governmental & Organizational Report. Markusson et al 2012 Analytical framework was adapted to analyze the three concerned uncertainties and understand how they were managed. Financial and economic uncertainties were surfaced after the project termination and Government Accountability Office Report on FutureGen cost estimation. After the report there were sequences of policy, regulatory, financial and economic uncertainties. The study results show that there are unexpected costs increase due to accidents and delay in the project operating, which are termed as indirect financial uncertainties. This study suggests that taking indirect financial uncertainties in planning a CCS project could help in managing other uncertainties.

The analyses of three major uncertainties also show that the only commercialized CCS project consume more than a decade time while delay in the project could increase the cost engendering a new uncertainty of time frame. Consideration of time frame uncertainties in project is important to keep the project on track and manage other uncertainties. Overall time frame uncertainties could help to achieve cumulative carbon emission targets. Further the study results show strong inter-linkages between uncertainties that reinforce and affect one another.

FutureGen 2.0 great achievements are the establishment of regulatory framework to govern the CO_2 storage site. In 2011 EPA establish regulation for storage well while Illinois State approved Clean Coal FutureGen for Illinois Act of 2011 for liabilities. These act and regulation were meant to manage environmental, health and safety risk associate with CCS technology ensuring feasibility of environmental dimension sustainability. Further the capability of oxyfuel combustion to remove the impurities from CO_2 stream offset the cost increase in FutureGen. The cost of CCS is estimated to decline in future making CCS a sustainable climate mitigation option.

Moreover studying three major uncertainties in FutureGen 2.0 project reveals the sustainability implication of CCS. In coherence with three dimensions of sustainability economic, environmental and social implications of CCS were evaluated. The important CSS implication is excessive water consumption and is said to lead to water competition among water required sector incurring water contamination and increase in cost of water permit. Oxy fuel combustion is considered water efficient however it is expensive due to parasitic energy used by ASU. Similarly holistic CCS system could have negative impacts on environment due to increase mining of fossil fuel, Air pollution, acid rain, water contamination etc. Another important implication of CCS is that CCS has diverted RD & D funding and incentives from other clean energy technology. Moreover the success of FutureGen 2.0 would enhance the CCS development that is considered to lead to carbon lock-in. However it is argued that CCS would transit towards to other clean energy technology rather than lock-in. Although the sustainability implication of CCS limit its role to carbon emission only however the FutureGen 2.0 project uncertainties management and development of regulation ensures safety of environment, health and property.

Further studies are suggested to analyse the effect of FutureGen 2.0 on CCS TIS. Effect of CO_2 on the below and above storage surface environment, the ratio of water consumption to that of cost and water quality are study areas that are highly encouraged to analyse. Studies related to CCS market creation, resource mobilization and entrepreneurial activities are needed to fill the knowledge gap. Further it is also important to understand how the transition period towards low carbon technologies will look like and what will be the future of CCS. Studies are also suggested to evaluate sustainability of overall CCS deployment in comparison to renewable and other low carbon energy technologies.

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Appendix: A

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Appendix 1: Recognition point marked in a unit Scientific Study

①

(Hanson & Brygelsson 2009)

Hansson and brygelsson points out some of the previous regarding the uncertainties in future prediction of new energy technologies. The gap between the uncertainties and the optimism expressed by the experts? and expressed in influential policy documents and research reports is neither unique nor necessarily to be considered a paradox; it is a generic phenomena when developing new complex energy technologies . the enthusiasm characterizing CCS shows similarities to that accompanied the introduction of nuclear power more than 50 years ago. In retrospect the research community 's ability to predict the future development of emerging technologies has been poor.

Hanson and Brygelson identified few uncertainties CCS faces based on the respondent CCS experts. i.e. cost, storage and technical, organizational and environmental complexity.

According to Hanson and Brygelson futurecost of CCS is a subject of energy system modeling and scenario construction, a research area facing many inherent problems. In a study conducted to know exerts views about uncertainties showed awareness of the limit of cost scenarios. Varying from the number of CCS plants unachievable to impact of input assumptions in scenarios.

In SRCC 2005 scenarios shows the learning rate has significant impact on the long term deployment of CCS and might increase the economical potential by a factor 1.5 however SRCC states that actual deployment will probably be lower than the modeled economical potential because several uncertainties are not included.

The historical learning rates are often used to estimates future learning curves and are in general criticized for not being accurate since they are baced on lack of detailed data e.g., short time series or even for being negative. And even based on an analogy from the flue gas desulphurization FGD development in the 1980s and 1990s. the FGD learning rate was 12-13% which might be a high assumption when considering the average learnging rate of coal related technologies that historically ranges between 3.75 % and 15.1%. Further more the accessibility of different CCS technologies is limited and it is difficult for independent researcher to assess the validity of assumptions and cost estimates.

Storage capacity is another probability based assumption between 66% and 90% store the emissions (2000GT CO2). The assumption is based on vastly

Storage

(9)

Hansson & Bryngelsson point out in a study of framing of uncertainties and possibilities that there is a knowledge gap most of the research findings are highly uncertain. CCS as an early stage of development impart an inherent uncertainty of full scale integrated CCS system for power generation and operation that expert deep realisable

Hansson & Bryngelsson argue that gap between Uncertainties and optimism is neither unique not necessarily to be ~~expressed~~ considered a paradox, it is a generic phenomena when developing new complex energy technologies. The enthusiasm characterising ccs shows similarities to the optimism that accompanied the introduction of nuclear power more than 50 years ago. Research has also been conducted on Uncertainties role in implementing emerging renewable technology. In retrospect the research community's ability to predict future development of emerging technologies has been poor. Scenarios are tools for dealing with uncertainties and support strategic decision making.

Optimism & Uncertainty
Hansson & Bryngelsson, 2009

Awareness/communication.

Awareness of uncertainties and potential over-optimism has to reach policy makers as they have scientific scenarios and expert comments as a significant basis for decision making. The awareness also has to reach public debate since the mass media coverage today is dominated by CCS. optimism Scientific Uncertainties may be visi