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Hydrocarbon Liquefaction:

-CTL & GTL as peak oil mitigation?

Dr Mikael Höök, Associate Professor

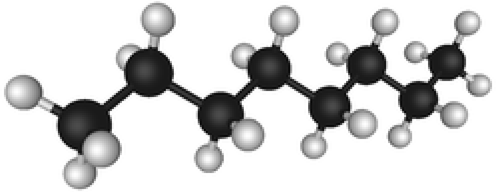
Global Energy Systems, Uppsala University, Sweden

Hydrocarbon liquefaction

- Generation of liquid fuel from solid or gaseous feedstock

- Coal-to-Liquids (CTL), Gas-to-Liquids (GTL)
  - Biomass-to-Liquids (BTL) and other options (XTL) are also technically achievable

- Such synthetic HC liquids can be used replace petroleum-based fuels



Simplified chemistry

- Bergius reaction (direct liquefaction / hydrocracking)

$$nC + (n+1)H_2 \rightarrow C_nH_{2n+2}$$

  – Partial breakdown of long HC-chains into shorter, liquid ones via hydrocracking

- Fischer-Tropsch reaction (indirect liquefaction)

$$(2n+1)H_2 + nCO \rightarrow C_nH_{2n+2}$$

  – Generates HC-chains of desired length by combining gaseous building blocks

Coal-to-Liquids

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- Three main approaches
  - Pyrolysis (Karrick-process)
  - Direct Coal Liquefaction (DCL)
  - Indirect Coal Liquefaction (ICL / Fischer-Tropsch)

- Pyrolysis is primarily done to upgrade solid fuels, but gives a maximum of 20% heavy tar liquids as a minor by-product

- Due to low yields and low quality of produced liquids, pyrolysis is not a feasible pathway

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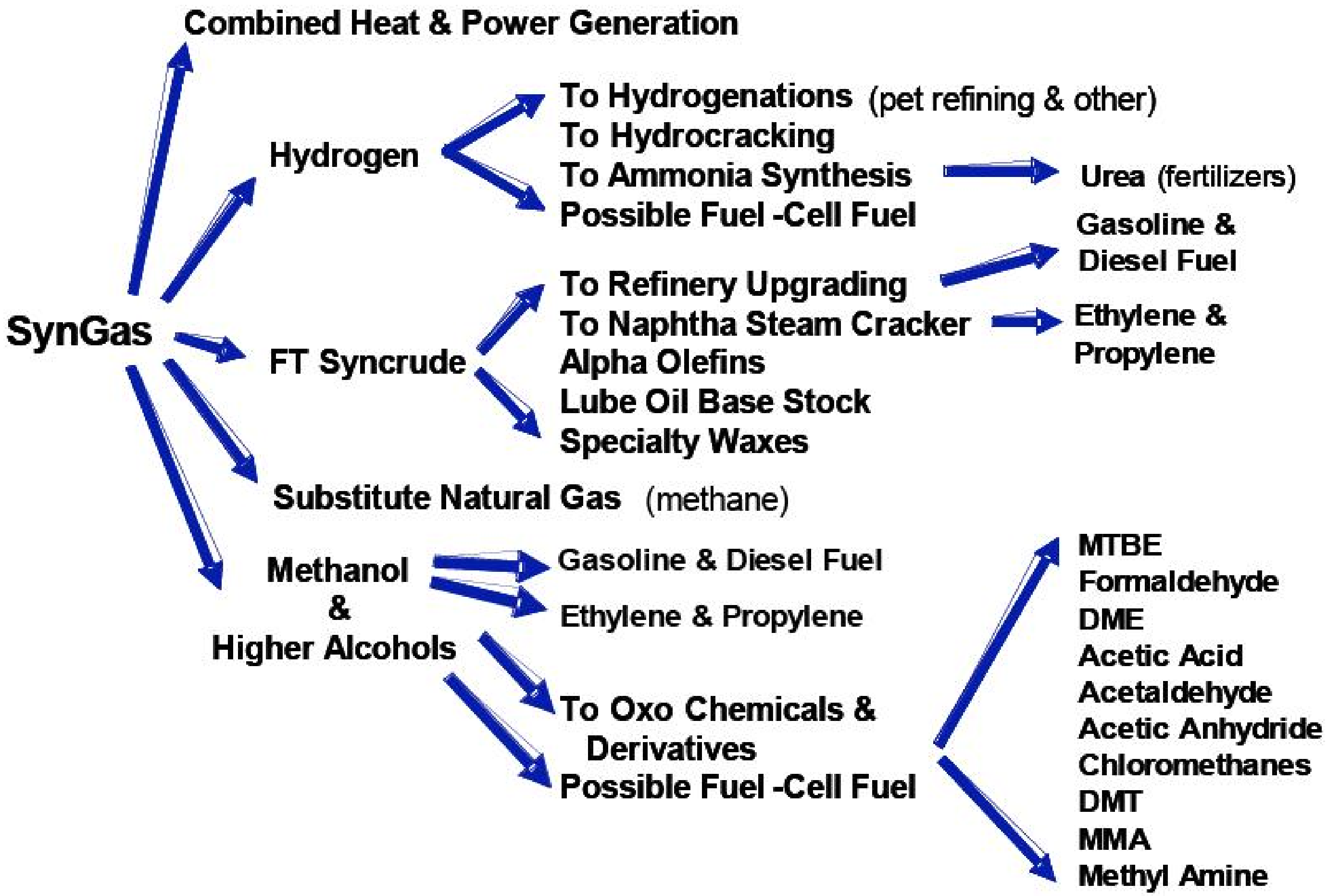
Current infrastructure

- More oriented towards ICL and Fischer-Tropsch synthesis
  - Several countries (such as China and South Africa) developed chemical industries around gasified coal instead of natural gas (Europe/USA)
  - More experience with gasification than indirect liquefaction

- SASOL solely developed and implemented ICL-technologies from 1960s, while DCL never made it past pilot/demoplants until 2000s

Syngas offers many possibilities



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Theoretical CTL efficiencies

- DCL can efficiencies over 70%
  - Creates a synthetic crude oil that requires further refining to give motor fuels
  - Additional refining reduces overall efficiency
  - Product has very low sulphur content, but generally rich in aromatics
- ICL reach a maximum efficiency of 60%
  - The raw distillate can be used as a motor fuel directly
  - Virtually free from sulphur and aromatics due to predominantly linear HC-chain structure

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Current technology status

- CTL has only been used commercially by a very limited number of companies, primarily SASOL
  - Worldwide capacity ~210 000 barrels/day
  - South Africa ~180 kb/d, China 20 kb/d, others 10 kb/d
- The first commercial GTL facility was established in 2007 as a joint-project by SASOL and Qatar Petroleum
  - Worldwide capacity = ~ 210 000 barrels/day
  - Qatar ~180 kb/d, Nigeria ~30 kb/d

The issues at stake

- How many barrels can one get from a ton of coal?
- What are typical conversion rates for CTL and how much coal will be consumed for a globally significant production output?
- Will development be economically feasible?

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Joint work in progress

- Results presented here are from upcoming work done together with:
- Dean Fantazzini, Moscow School of Economics
- Simon Snowden, University of Liverpool
- André Angelantoni, PostPeak Living

- It is a review of all available CTL/GTL works
  - 25 recent GTL studies
  - 16 recent CTL studies

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Conversion rates

- Range from 1-3 barrels/ton coal in available literature

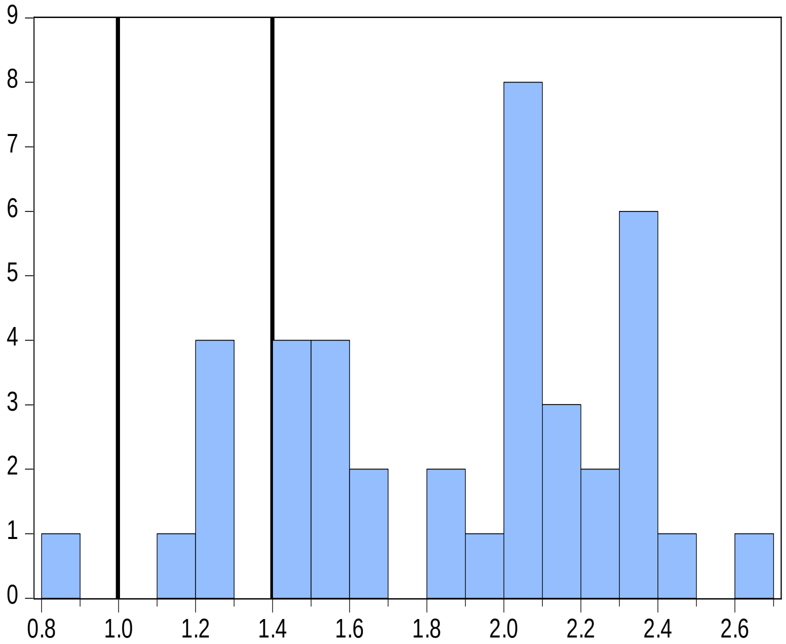
- Generally lower yield with low-ranking coals

- Actual consumption is highly dependent on the specific plant design, process layout, CTL method, feedstock, etc.

- Only one commercial example is available, i.e. SASOL at **1-1.4 barrels/ton coal** *derived from bituminous coal*

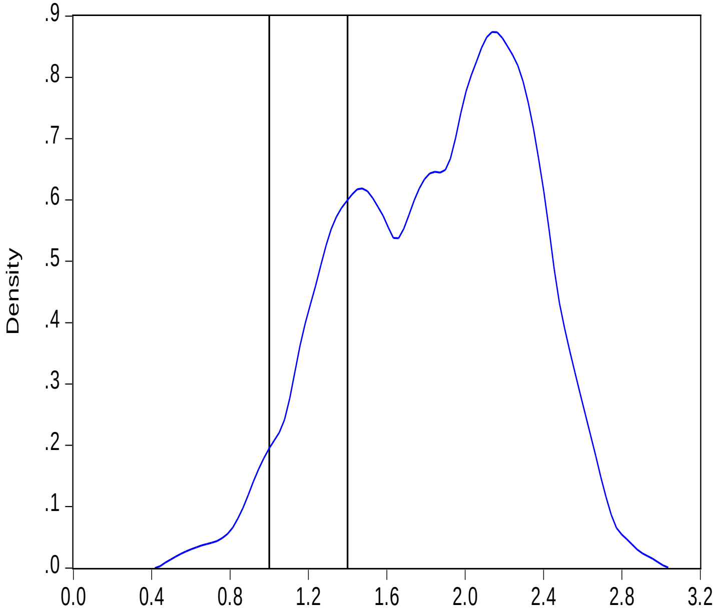
Optimistic studies

- Available and reviewed CTL studies generally use very optimistic conversion rates
- Far outside the commercially proven interval



Series: YIELD
Sample 1 40
Observations 40

Mean	1.855925
Median	2.040000
Maximum	2.620000
Minimum	0.840000
Std. Dev.	0.435923
Skewness	-0.348268
Kurtosis	2.122198
Jarque-Bera	2.092834
Probability	0.351194

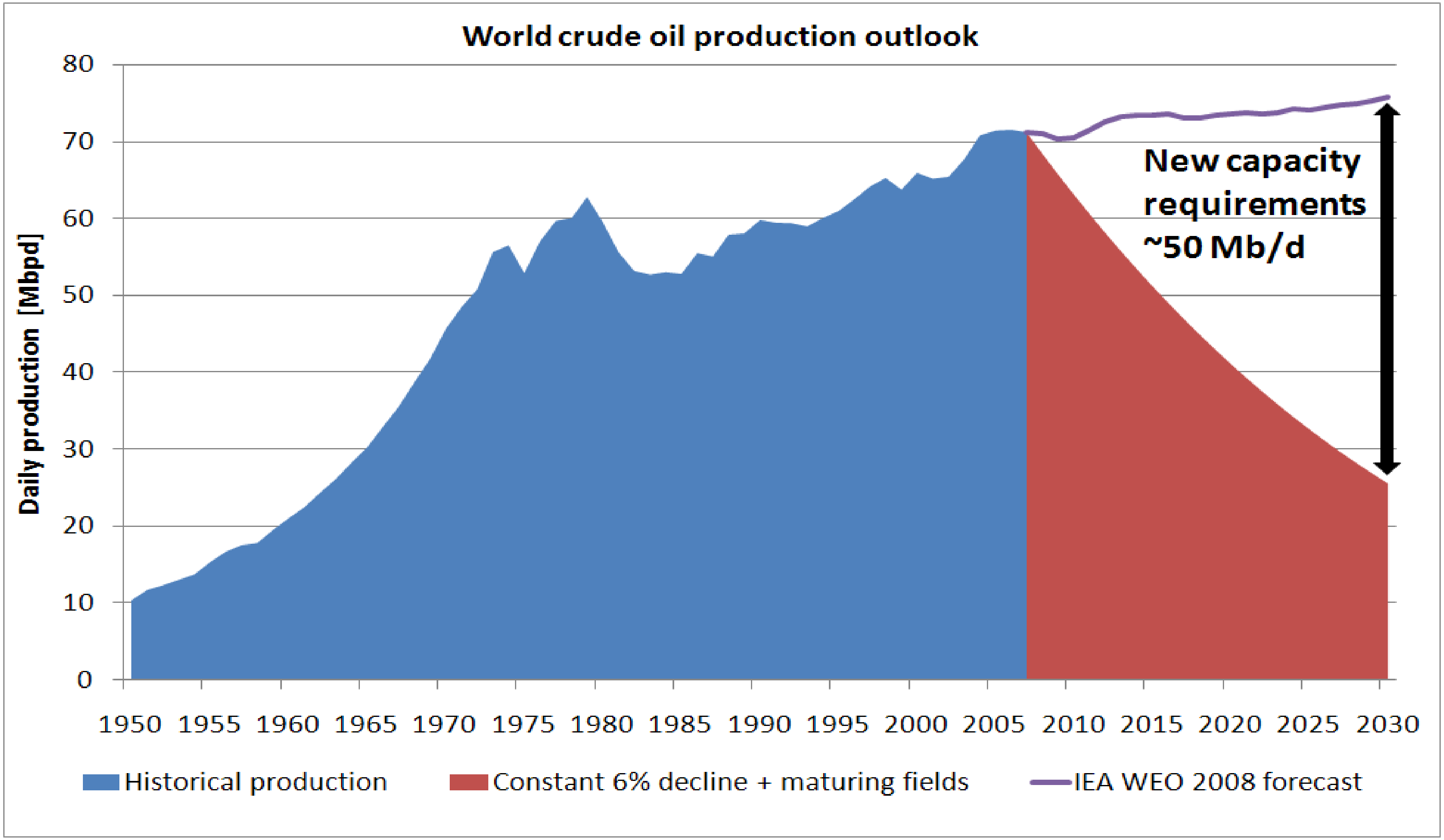


Source: Höök, Fantazzini, Angelantoni, Snowden (2012) paper in preparation

Some examples

- EIA use over 2.5 barrels/ton coal
- National Coal Council use 2.3 barrels/ton coal
- IPCC and many others do not even specify the conversion rates they used
- If numbers are given but they are often *very optimistic* compared to practical experience

Future production needs?

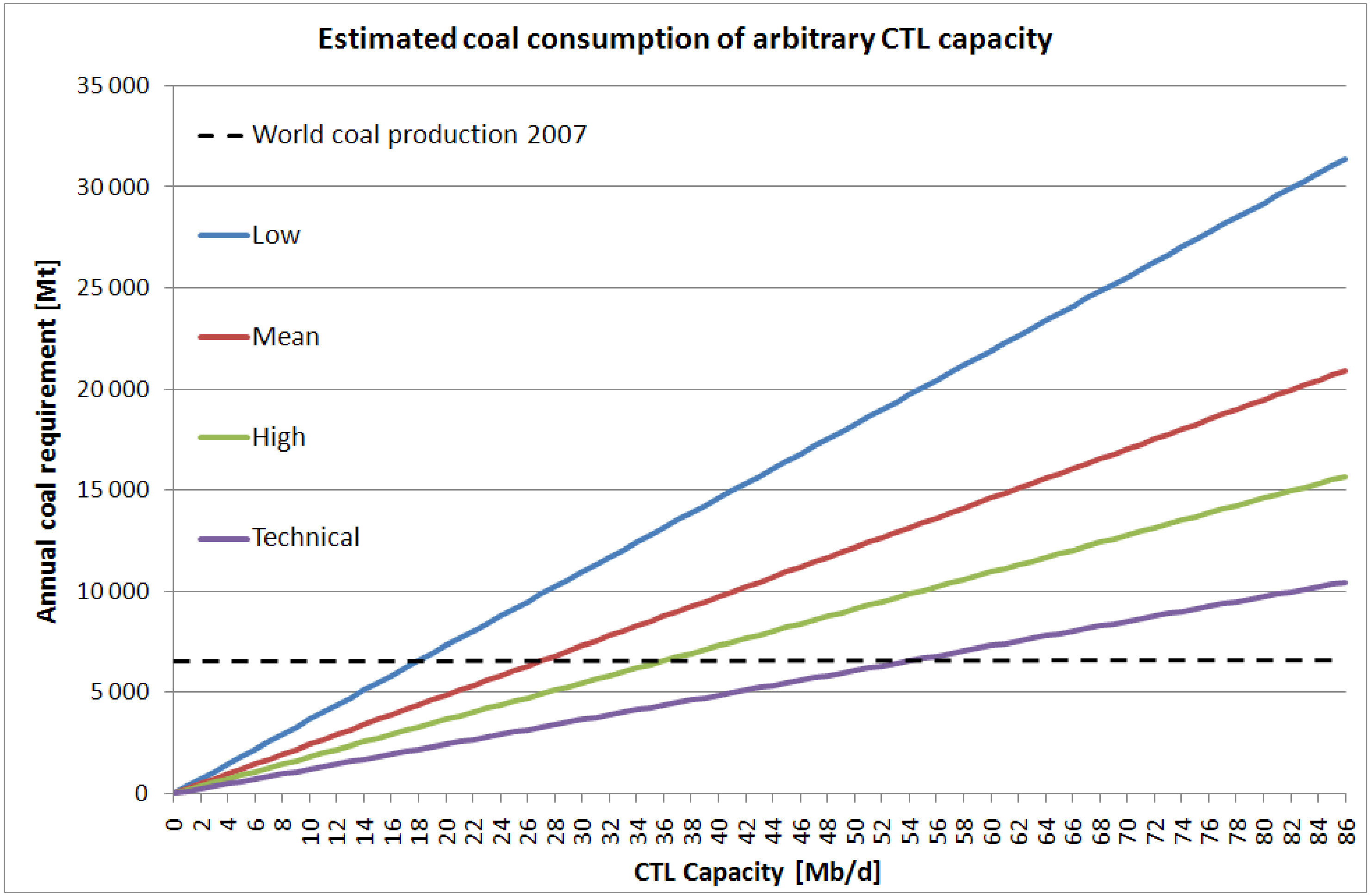


Source: Höök, Hirsch & Aleklett (2009) Giant oil field decline rates and their influence on world oil production, *Energy Policy*, Volume 37, Issue 6, Pages 2262-2272

Needed CTL capacities

- World oil production declines with 3-7 Mb/d annually
- Requires 1000-2500 Mt of coal annually (10-25% of present world coal production)
- Clearly not feasibly to divert so much coal to offset just a single years decline
- Prevents CTL from becoming a major solution

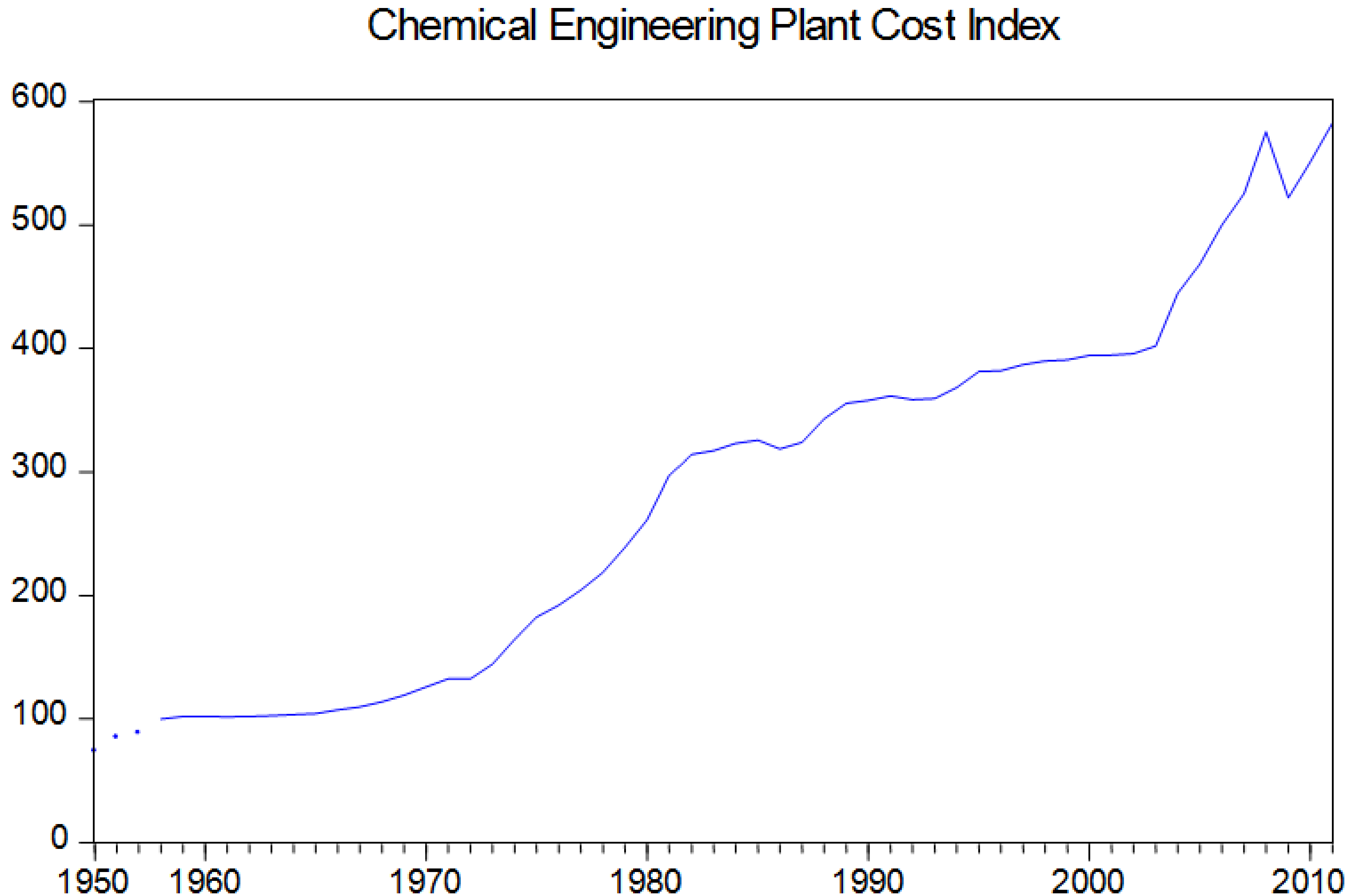
Semi-empirical outlook



Low = 1 b/ton
Mean = 1.5 b/ton
High = 2 b/t
Tech = 3 b/ton

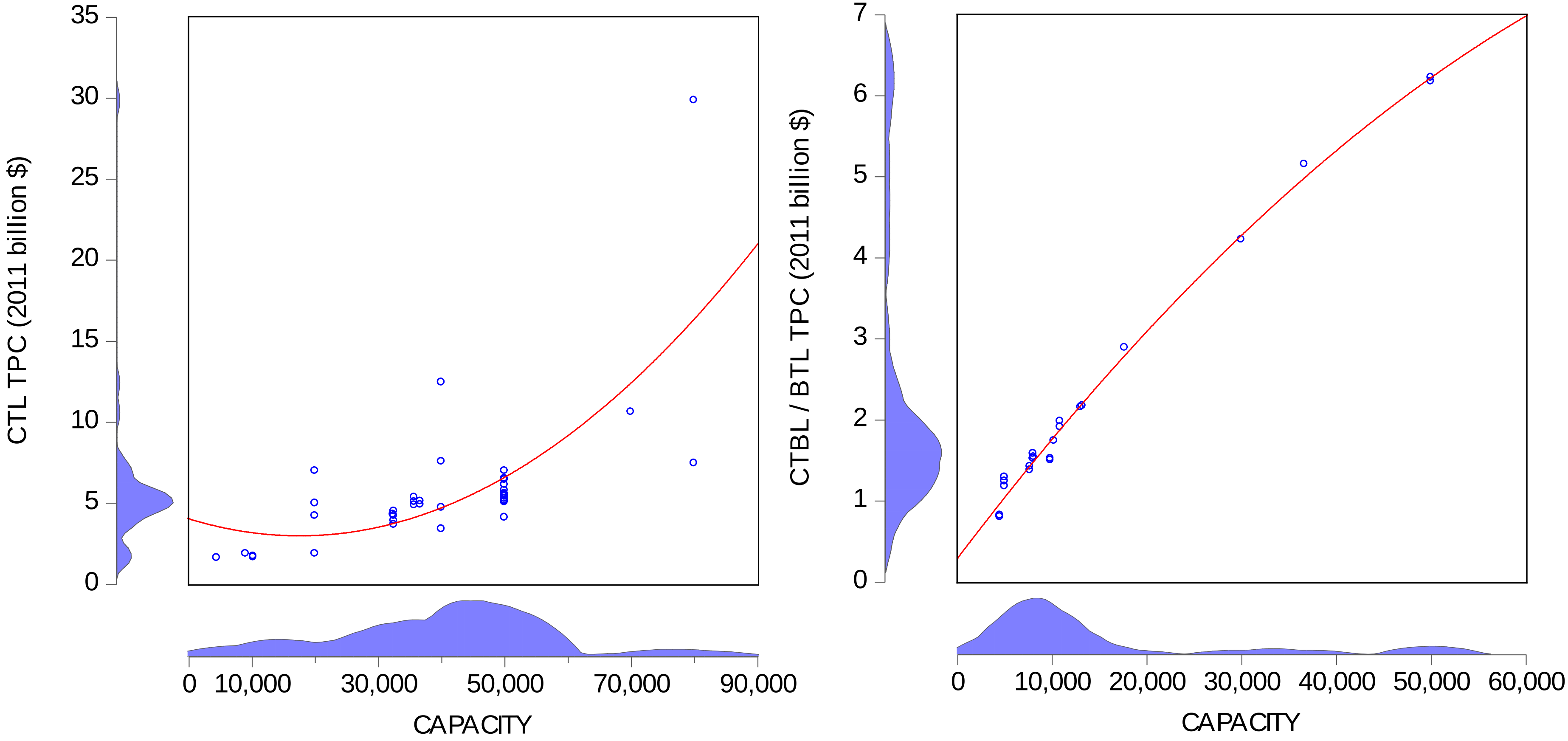
Source: Höök & Aleklett (2009) A review on coal-to-liquids and its coal consumption, *International Journal of Energy Research*, 34(10), 848-864.

Plant construction cost evolution



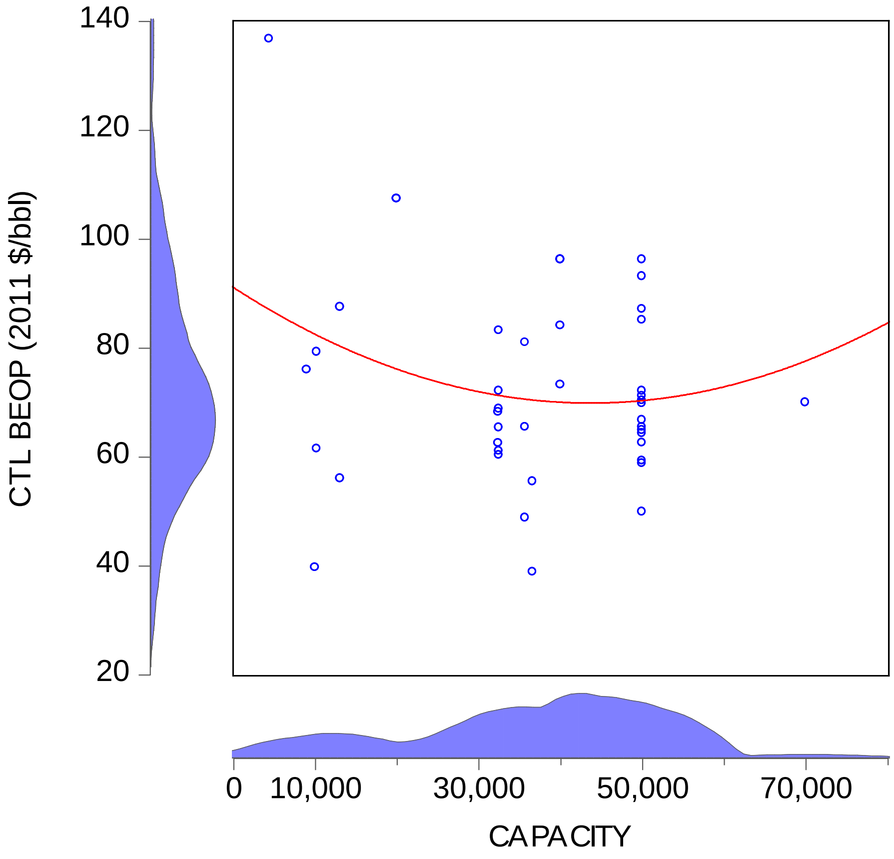
Chemical Engineering Plant Cost Index (CEPCI) is a composite of indices for equipment costs, construction labor costs, buildings costs, and engineering & supervision costs

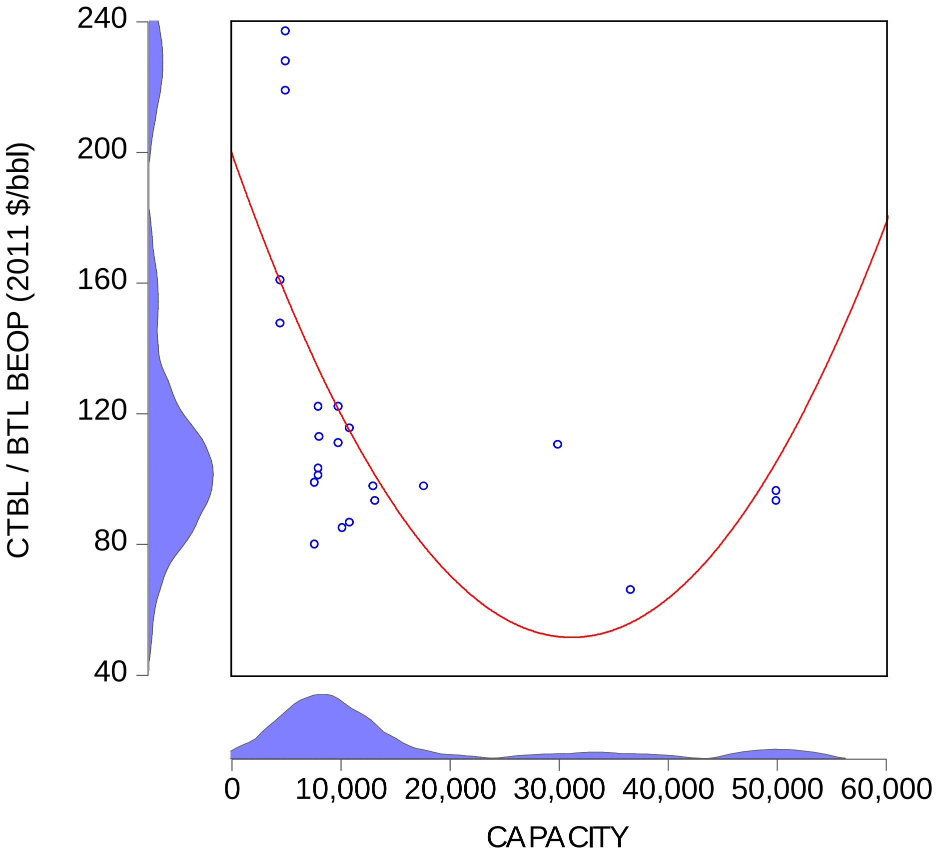
CTL & CBTL/BTL



- ***Left***: *CTL capacity costs [$2011 dollar/barrel per day]*
- ***Right***: *CBTL/BTL capacity costs [$2011 dollar/barrel per day]*

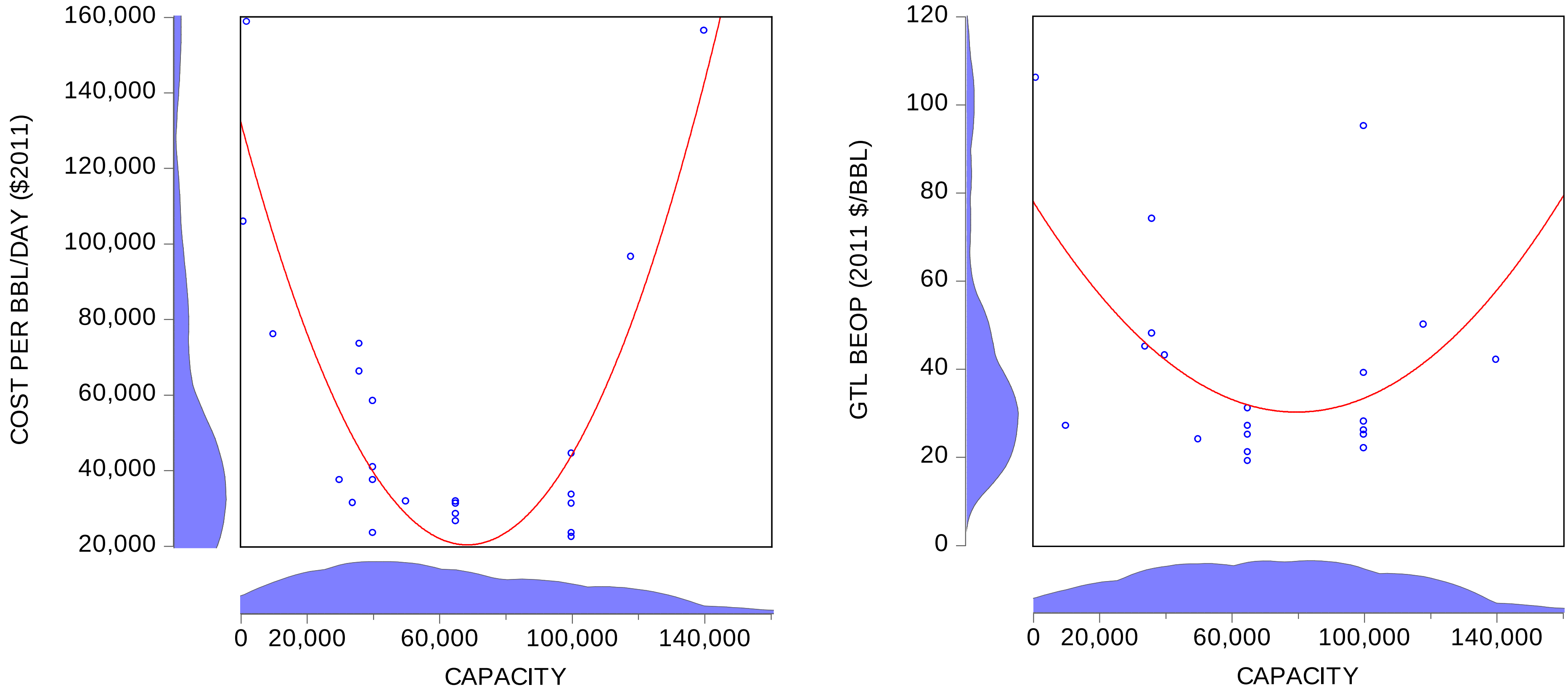
CTL break even oil prices





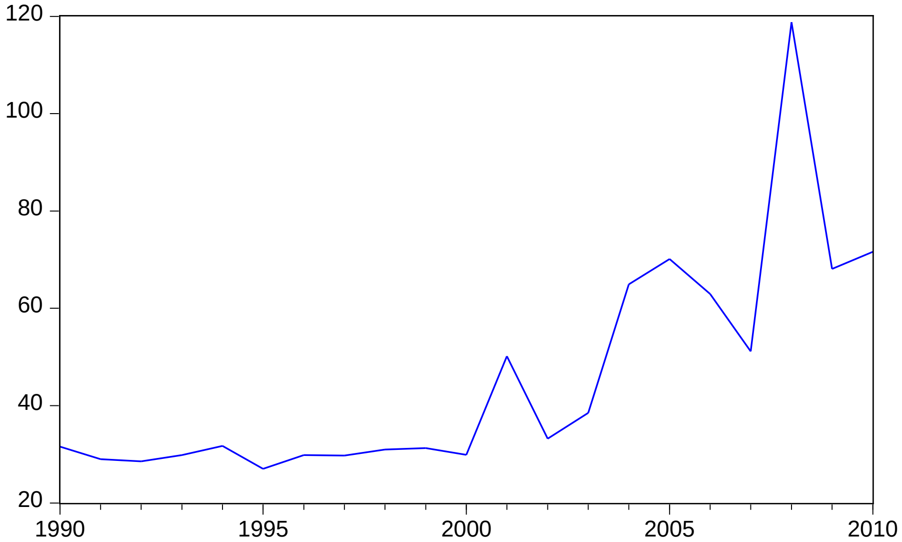
- ***Left**: CTL Break-Even Crude Oil Price [$2011 dollar/barrel]*
- ***Right**: CBTL/BTL Break-Even Crude Oil Price [$2011 dollar/barrel]*

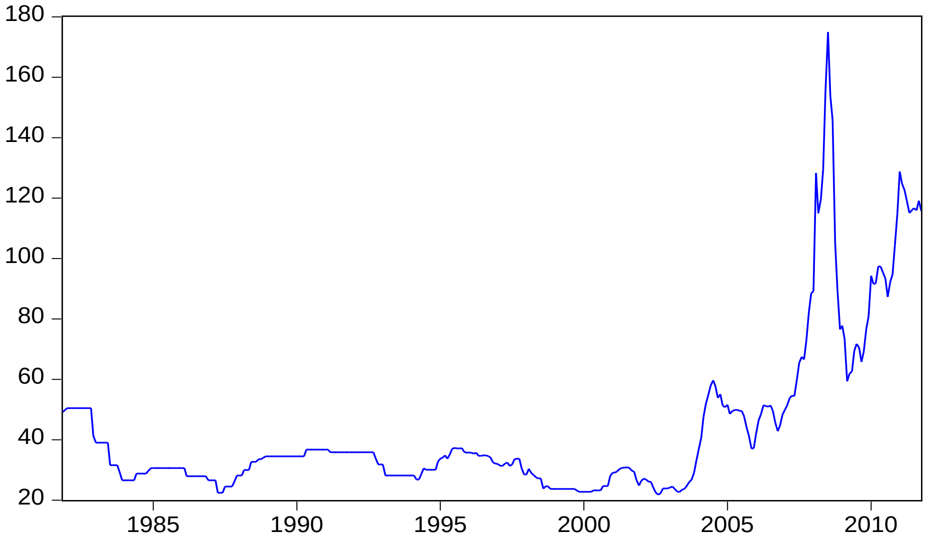
GTL costs



- ***Left***: *Investment cost per barrel [$2011 dollar/barrel per day]*
- ***Right***: *Break-Even Crude Oil Price [$2011 dollar/barrel]*

Coal cost evolution





- ***Left**: Average yearly US Central Appalachian coal spot price, ($/short ton), 1990-2010, source: Platts and BP statistical review of World energy. Prices are for 12500 Btu, 1.2% SO2, FOB.*
- ***Right**: Monthly price for Australian thermal coal ($/short ton), November 1981 - October 2011, Source: globalCOAL and Indexmundi. Prices are for 12000 Btu, less than 1% sulfur, FOB.*

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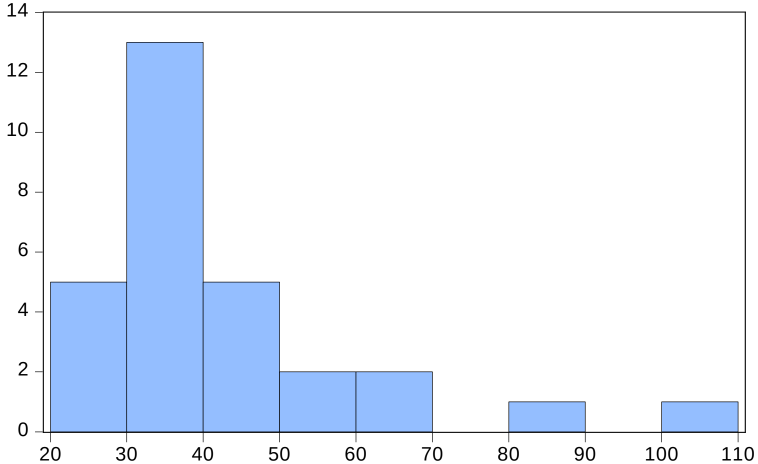
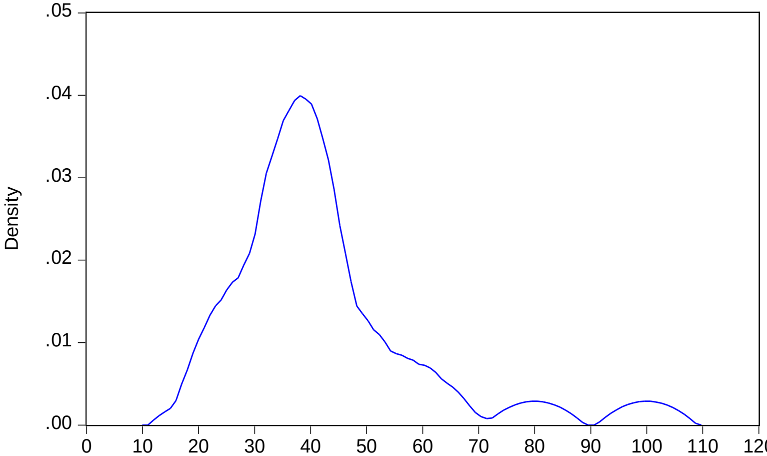
Assumed coal costs



Series: COAL_PRICE
Sample 1 29
Observations 29

Mean	42.25379
Median	38.85000
Maximum	100.0000
Minimum	20.00000
Std. Dev.	16.87043
Skewness	1.729642
Kurtosis	6.438200
Jarque-Bera	28.74366
Probability	0.000001



- Unfortunately, most of the reviewed papers considered much lower prices than those observed in this decade

- The mean price for bituminous coal across papers was close to 42 $/ton, while more than 60% of the prices considered were lower than 40$

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Cost escalations

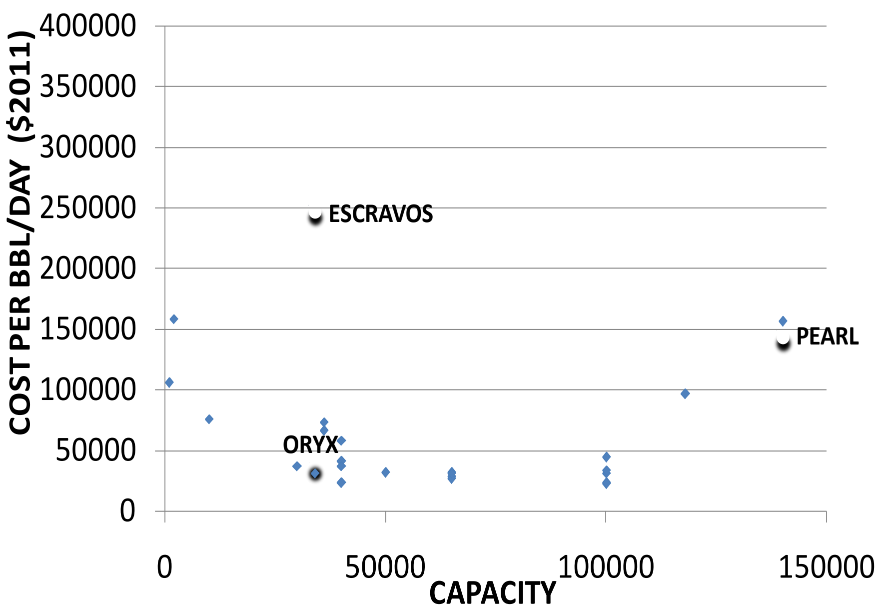
- Due to costs escalation, all analyses about CTL performed before 2005/2006 are largely unrealistic

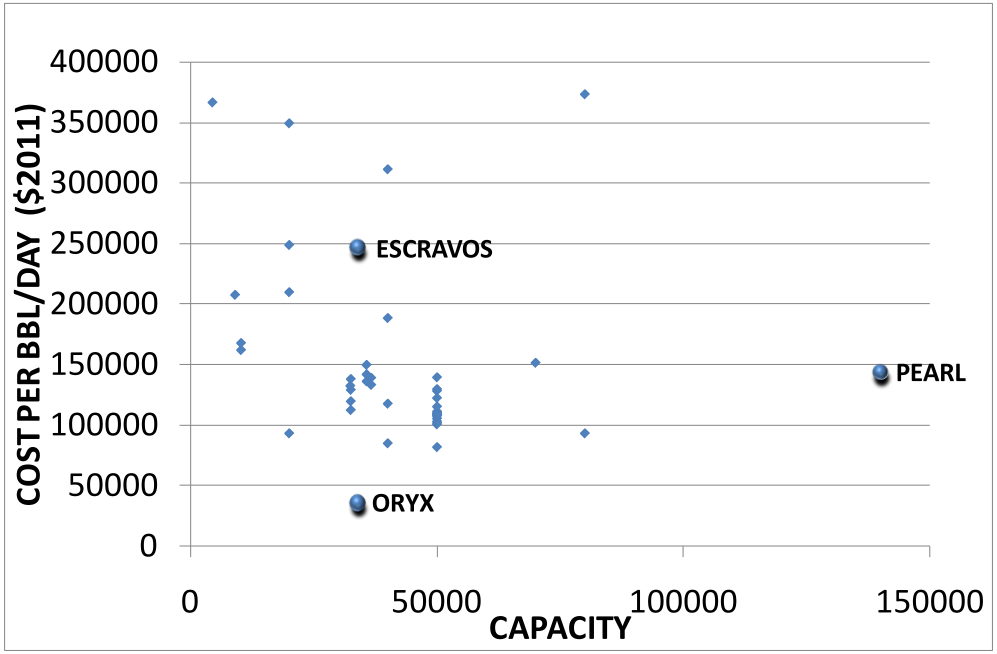
- CTL developments are often assumed to behave as mature industry (only true in South Africa). *First of a kind* and *early mover* financial conditions can increase costs by 50%

- Wu et al. (2011) show that the Required Selling Price of FT fuels increase linearly with the mine-mouth price of coal, *when holding the other system assumptions constant*

GTL economics

- Some are claiming that GTL is economically advantageous compared to CTL
- Data from 3 real projects give conflicting info but show good agreement with CTL data





Reversal of the Chinese CTL policy

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- As of 2008, China suspended all CTL projects except two

<u>Reasons behind the policy reversal</u>

1. Increasing water scarcity
2. Shortages in coal supply and industry changes
3. Development craze from local governments

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Conclusions

- High inherent coal consumption prevents CTL from becoming a major liquids producer
- CTL can only be feasible for major coal producers and coal reserve holders
- Limits CTL to a few countries
- Possible underestimated coal costs in CTL studies

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Conclusions II

- Optimistic assumptions in economic studies have likely exaggerated the advantages of CTL/GTL
- Economic differences between CTL and GTL seems rather small
- Our analysis highlights the strong risk for a liquefaction plant to become a **financial black hole**
- It is understandable why countries such as China has slowed down liquefaction plans

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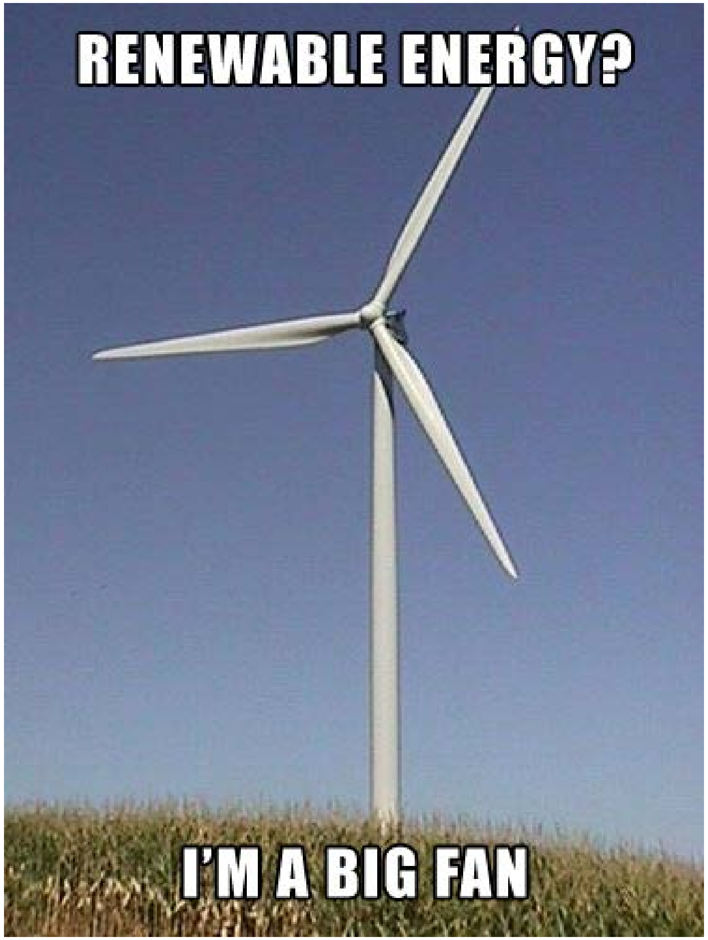
Thanks for your attention!



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