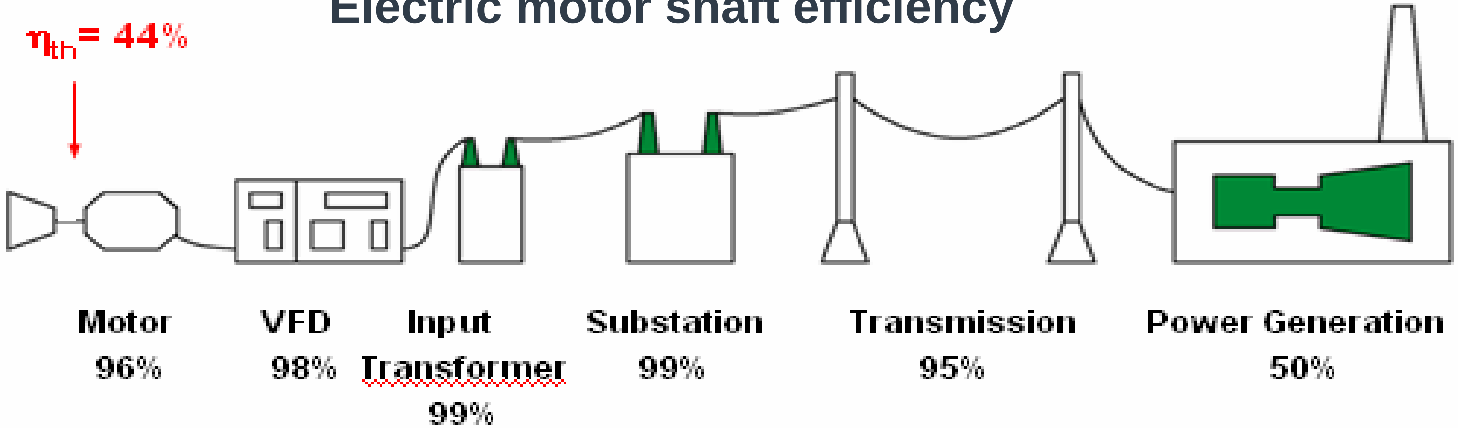
Why Electric Compression

or otherwise
why still Gas Engine driven Compression

Gas/Electric Partnership
Special Workshop
Electric Compression Economics,
August 27 2009, Houston

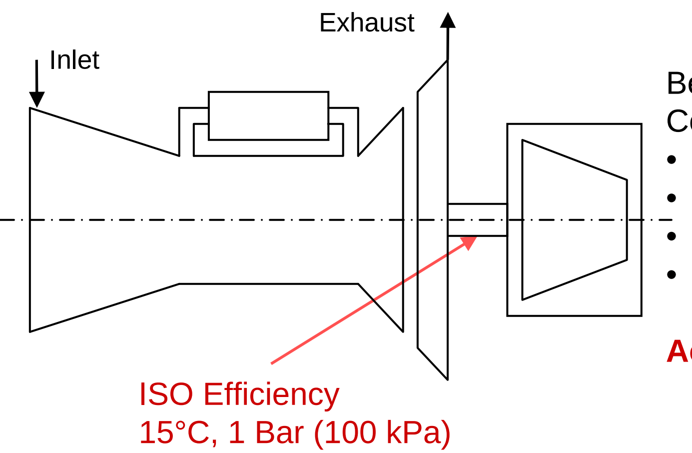
Overall efficiency comparison

Electric motor shaft efficiency



Thermal Efficiency η_{th} = (0.96)(0.98)(0.99)(0.99)(0.95)(0.50) = **44%**

Gas turbine shaft efficiency

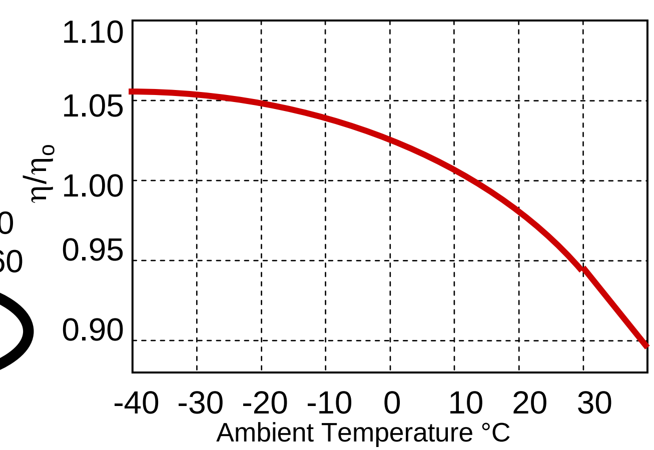


Best available ISO efficiency ~ 36%

Corrections for

- Inlet & exhaust systems: 0.98
- Auxiliary loads: 0.99
- Temperature (-40 to +40°C) 1.05 - 0.90
- Part load: 1.00 - 0.60

Actual shaft efficiency **36% - 19.0%**



Fundamental changes in the energy market

The situation until late’80s

Since the gas turbine demonstrated its reliability in industrial applications in the late ‘50s/early ‘60s, it has been the most widely used driver for gas pipeline applications in the mid to large power ranges. Smaller power requirements have been shared with gas engine reciprocating compressors. Although electric drives have long been commonplace on liquid lines, until recently they have rarely, if ever, been used for gas pumping. The reasons for this are well known:

- The gas pipeline/storage companies’ reluctance to be dependent upon an external source of power being supplied by a competing industry
- The strongly regulated electricity and gas market
- The cost of electric power compared with gas.

The situation since early ’90s has undergone fundamental changes in a process which is still ongoing in North America and in Europe.

- Deregulation of the gas and electric utilities has on the one hand caused the pipeline companies to make their systems more efficient and on the other has led to a significant reduction in the cost of electric power.
- The move from nuclear to gas fired power stations has made the two industries become more dependent upon each other. (present situation in europe)
- Gas and electricity are converging commodities and futures in both are traded on stock exchanges. This development has led to the formation of energy corporations as opposed to gas or electricity utilities. (present situation in europe)

Technologies
Gas Transport / Storage market


Gas Transport Application

- Gas Turbine driven Centrifugals
- Gas Engine RECIP‘s
- Electric Motor driven Centrifugals
- Electric Motor driven RECIP‘s

Gas Storage Application

- Gas Engine RECIP‘s
- Eletric Motor driven RECIP‘s
- Electric Motor driven Centifugals

Order of importance

Gas Transport Application

- Electric Motor driven Centrifugals
- Gas Turbine driven Centrifugals
- Electric Motor driven RECIP‘s

Gas Storage Application

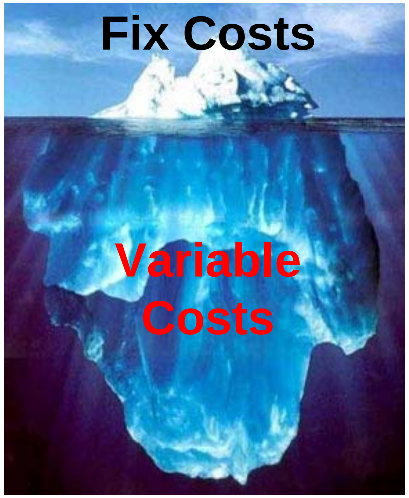
- Electric Motor driven Centrifugals
- Gas Turbine driven Centifugals
- Electric Motor driven RECIP‘s

clear tendency to EM driven centrifugals, RECIp‘s only used in case flow‘s are too small for centrifugals

Fundamental evaluation criteria's to make the decision for Gas Engine/Electric Compression

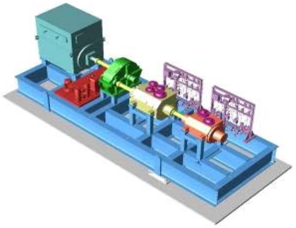
Economical evaluation based on a full Life Cycle Cost analysis has to be performed for all alternative technologies

- **CAPEX- Analysis:** **considering all overall installation costs, like costs for compression train, building, grid connection Install.&Comm. ,Permit**
- **OPEX-Analysis:** **costs for energy, personnel, buildings, emmissions, interest rates, downtime**
- **MAEX-Analysis:** **spare parts, personnel, downtime**



The following spreadsheet shall be regarded as a guideline, which aspects have to be considered for such an overall **qualitive** LCC analysis from equipment suppliers point of view.

CAPEX Comparison of Different Turbo Compressor Train Concepts

Train I	Train II	Train III
GT - TC	LS EM - Gear - TC	HS EM - TC
		

CAPEX for Compressor train

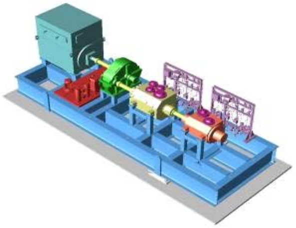
Centrifugal Compressor	0	0	0
Driver (GT,VSDS, EM)	-2	1	-1
Gear / (Gear not needed)	-1 (2)	-1	(2)
Bearing System	0	0	-2
Lube/Control/Working Oil system	-1	-1	2
Dry Gas Seal System	-1	-1	2
(Capital) Spare Parts	-1	-1	1

CAPEX for Plant

TC Building (area / height) hazardous area	-2	1	2
VFD Building (area / height) non hazardous	2	-1	-1
Power Supply Installation (Fuel Gas Piping / Electrical Cable)	1	-1	-1
Oil System Air Cooler	-1	-1	2
Equipment Installation & Commissioning	-2	1	2

weighting of train characteristics with each other in respect to capital investment costs (+2 most beneficial, -2 less beneficial)

CAPEX Comparison of Different Turbo Compressor Train Concepts ... continued

	Train I	Train II	Train III
	GT - TC	LS EM - Gear - TC	HS EM - TC
			

CAPEX for Building

Foundation Size / Civil Works	-1	1	2
Interconnecting Piping of Lube / Control / Working Oil to Air Cooler	-1	1	2
Noise mitigation	-2	-1	1
Interconnecting Piping DGS	-1	-1	2
Crane Capacity	-1	1	2

CAPEX for Auxiliaries

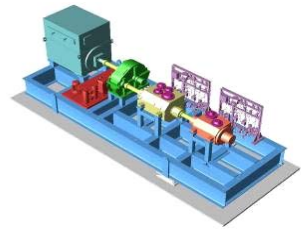
Intake Filter System	-2	2	2
Fire and Gas Detection System	-1	1	1
Emission Control	-1	1	2
Harmonic Filters (LCI only)	2	(-2) 2	2

Environmental related costs

VFD Cooling System Noise Emission	2	-1	-1
Oil Cooling System Noise Emission	-1	-1	2
Fulfillment of emission regulations	-2	1	2
Emission Credits	-2	1	1
Permitting Costs	-1	1	2

weighting of train characteristics with each other in respect to capital investment costs (+2 most beneficial, -2 less beneficial)

OPEX/MAEX Comparison of Different Turbo Compressor Train Concepts

Train I	Train II	Train III
GT - TC	**LS EM - Gear - TC**	**HS EM - TC**
		

Train full load cycle efficiency		
LOW due to low driver efficiency	HIGH due to high driver efficiency	HIGH due to high driver efficiency
Train part load efficiency		
LOW due to low driver efficiency. All trains experience reduced efficiency in throttling mode (recycle) at very low flow.	HIGH driver efficiency is nearly constant at varying power levels. All trains experience reduced efficiency in throttling mode (recycle) at very low flow.	HIGH driver efficiency is nearly constant at varying power levels. All trains experience reduced efficiency in throttling mode (recycle) at very low flow. Less critical due to incread speed range
Restart capability after forced shutdown and start density		
2 to 3 hour delay for restart due to driver thermal soak. Limited number of restarts per hour.	Restart ability varies with motor design. Limited number of restarts per hour.	Immediate restart. No limit on number of starts per hour.
Load assumption		
Approximately one-half hour after successful start.	Ability to start and come to full speed under load.	Ability to start and come to full speed under load.
Sensitivity to site conditions		
Available power reduced with increase in elevation, temperature, and humidity	Full power available at all site conditions	Full power available at all site conditions

OPEX/MAEX Comparison of Different Turbo Compressor Train Concepts ... continued

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	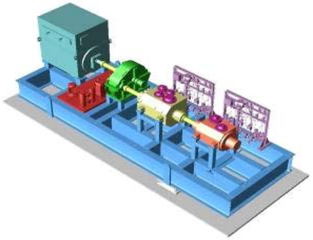	

Controllability		
Reasonably good, but depends on firing temperature and heat distribution	Speed controllability less accurate due to frequency adjustment range 0-60Hz(+/- 0.5 Hz) (200 rpm)	Excellent speed controllability due to high frequenzy operation at about 200 Hz (+/- 0.5Hz) (30 rpm)
Ease of remote operation		
Good	Better	Excellent (all electric concept)
Speed control range		
typically 70 - 105%	typically 70 - 105%	30 - 105%
Sarting reliability		
Good	Excellent	Excellent
Auxiliary consumption		
Lube oil, lube oil filter media, inlet air filter media, power for lube oil pumps, lube oil cooler fans. Nitrogen required for seal gas buffering. Instrument air consumption, for filter/purge pulse cleaning.	Lube oil filter media, power for lube oil pumps, lube oil cooler fans. Nitrogen required for seal gas buffering. Nitrogen required for seal gas buffering. Instrument air consumption, for motor purge and motor pressurisation needed	Cooling gas filter media. Reduced instrument air consumption due usage of only one TCV for motor cooling. No air purge requirements. AMB power supply.

OPEX/MAEX Comparison of Different Turbo Compressor Train Concepts... continued

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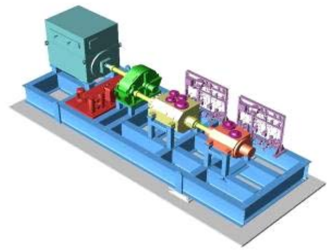
		

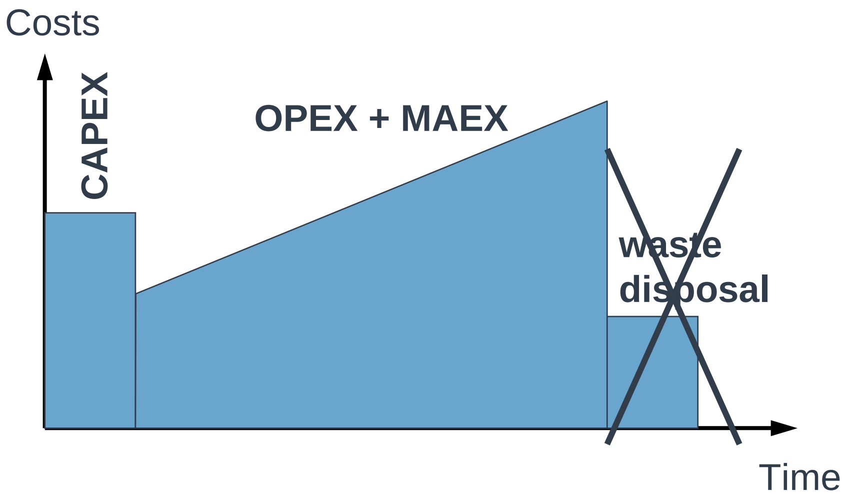
Eshaust emissions		
Seal gas must be vented or flared; CO2 and NOx emission.	Seal gas must be vented or flared.	Zero local emissions.
Maintenance costs		
higher	lower	lowest
Unit availability		
lowest	high	highest
Unit reliability		
lowest	high	highest
Ability to trade carbon credits		
lowest	high	highest
Fuel/Energy costs		
Function of local cost of electricity		
Risk of stricter Furure Emission Regulations		
high	low	low
Insurance risk		
higher	lower	lower

Life Cylce Costing: Definition

- **Common Definition**

Classification and summation of single cost factors of a examined object within its time of life into following fields

- acquisition (CAPEX)
- operation and maintenance (OPEX + MAEX)
- waste disposal (not considered)

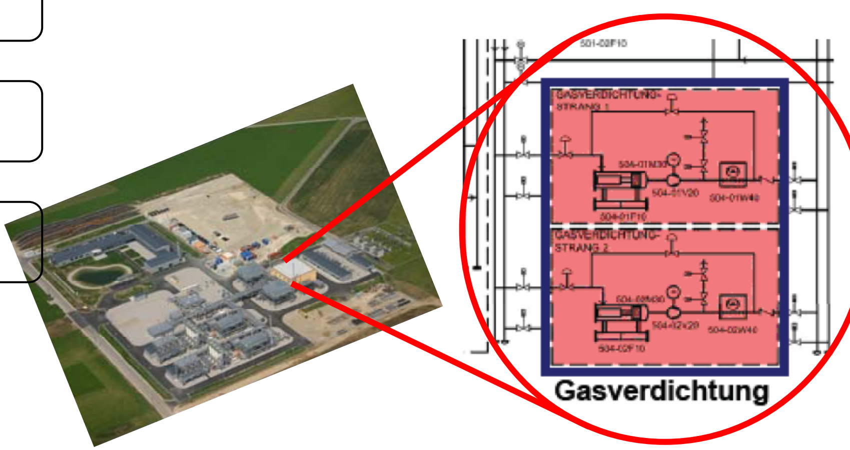


- used definition for the present analysis : LCC = CAPEX + OPEX + MAEX

Life Cycle Costing Analysis

Life Cycle Costing

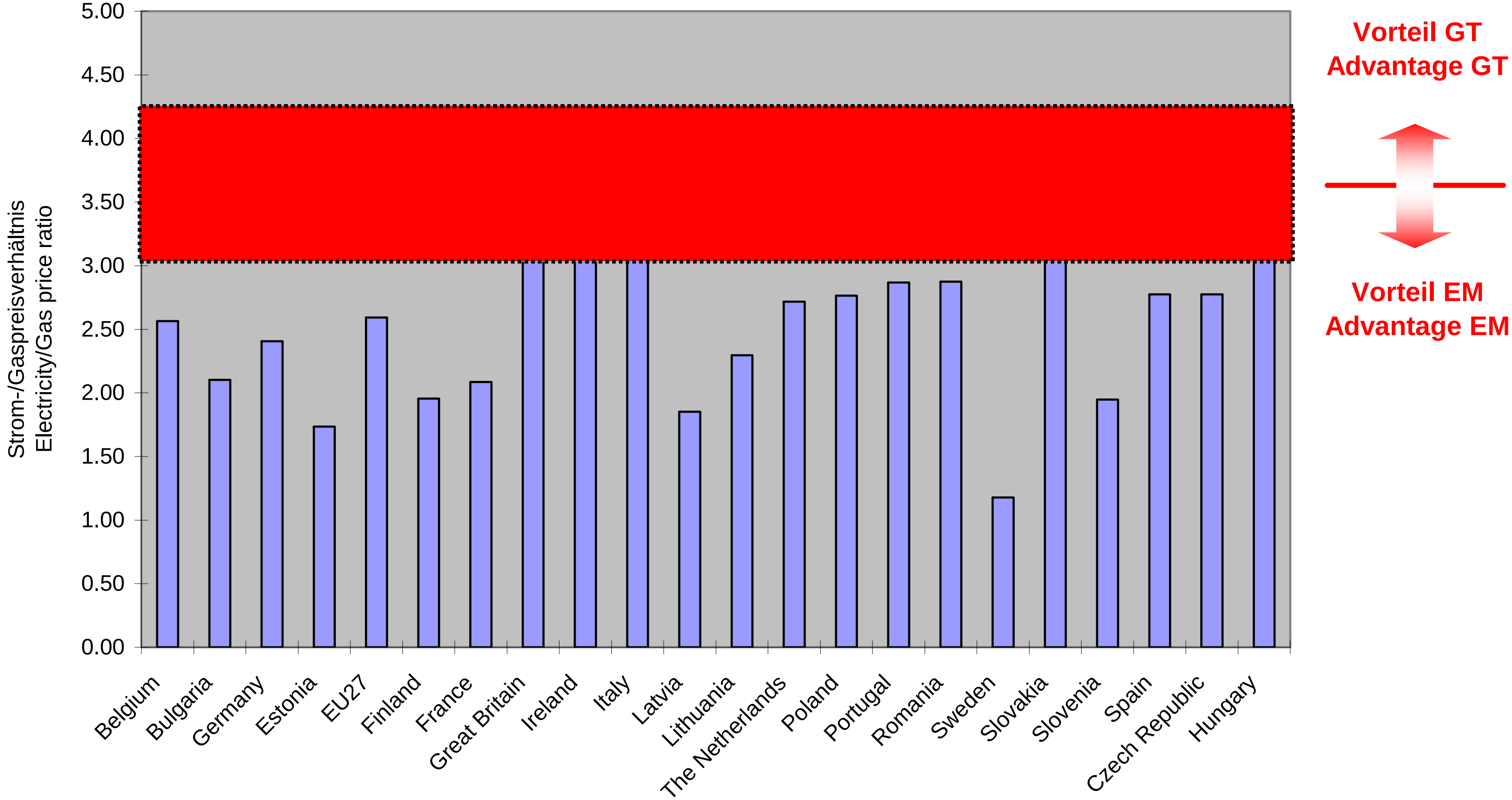
- CAPEX
  - costs of compressor train
  - costs of building
  - costs of connection to electrical grid
  - costs of erection & commissioning
  - costs for getting permissions
- OPEX
  - energy costs
  - costs of personnel
  - costs of buildings
  - costs of emissions
  - money interests
  - costs of downtime
- MAEX
  - spare parts
  - costs of personnel
  - costs of downtime



Energy Prices

Electricity/Gas price ratio Europe

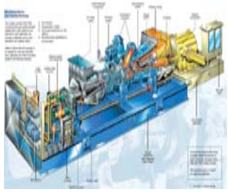
(The ratio decreased during 2008 due to heavy price fluctuations for oil and gas.)



Prices from Eurostat, Industry, 2008s1, incl. excise tax, excl. VAT

Case Study: Input data

Life Cycle Costing - Analysis Gas storage

Compressor String Concept			GT - Gear - TC	LS EM - Gear - TC	HOFIM
Distance to network plane	6	[km]			
Redundancy Concept (N+R)	1+1				
Country	Great Britain				
Storage Type *)	Depleted Gas Field				
AGV *)	0	$[Nm^3]$			
Injection rate	80'000	$[Nm^3/h]$			
Withdrawal rate	80'000	$[Nm^3/h]$			

Show total efficiency (1) | Calculate LCCs (2)

Program version 3.2 dated 2009-06-10

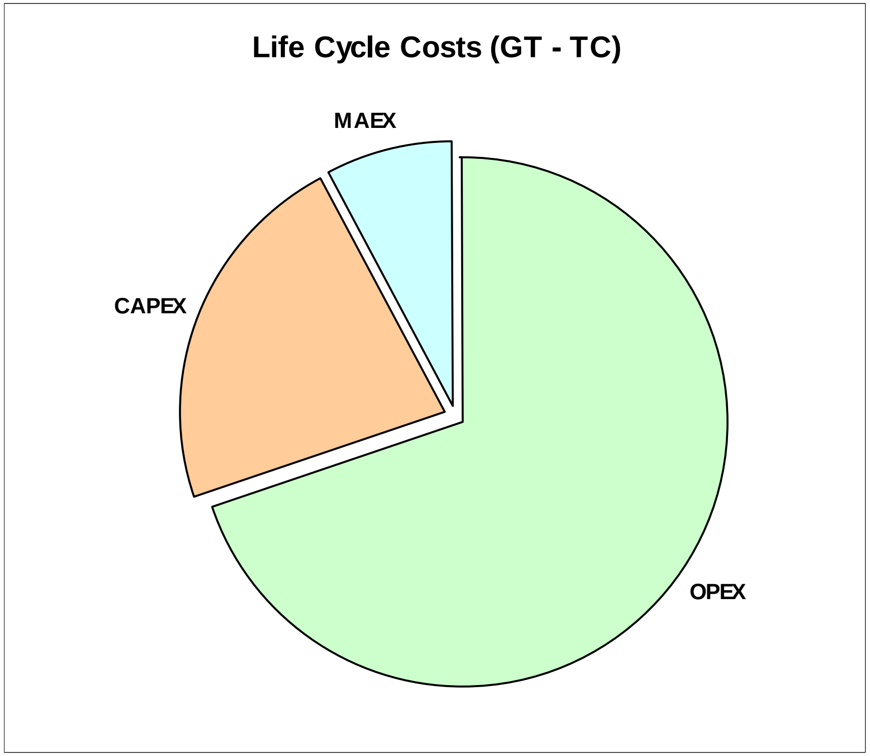
		GT - Gear - TC	LS EM - Gear - TC	HOFIM
Yearly start/stop frequency of the compressor facility	[-]	50		
Electricity price (industry, 2008S01, excl. VAT)	[€/kWh]		0.08530	
Gas price (industry, 2008S01, excl. VAT)	[€/kWh]	0.026		
Installed Power	[kW]	6'000	6'000	6'000
Technical availability of a string	[%]	95.0	98.0	98.5
Availability according to redundancy concept	[%]	99.750	99.960	99.978
Total efficiency of the compressor station	[%]	27.9	72.5	71.2
Yearly electricity price increase	[%]		3.50	
Yearly gas price increase	[%]	4.50		
Operating hours per operating year	[h]	3'000		
Operating years	[a]	20		
TOTAL CAPEX before operations begin (incl. N+R)	**[€]**	**20'699'357**	**19'834'143**	**20'942'429**
TOTAL OPEX after utilisation period (incl. N+R)	**[€]**	**64'418'993**	**67'414'596**	**65'989'210**
TOTAL MAEX after utilisation begin (incl. N+R)	**[€]**	**7'212'130**	**4'491'682**	**1'380'913**

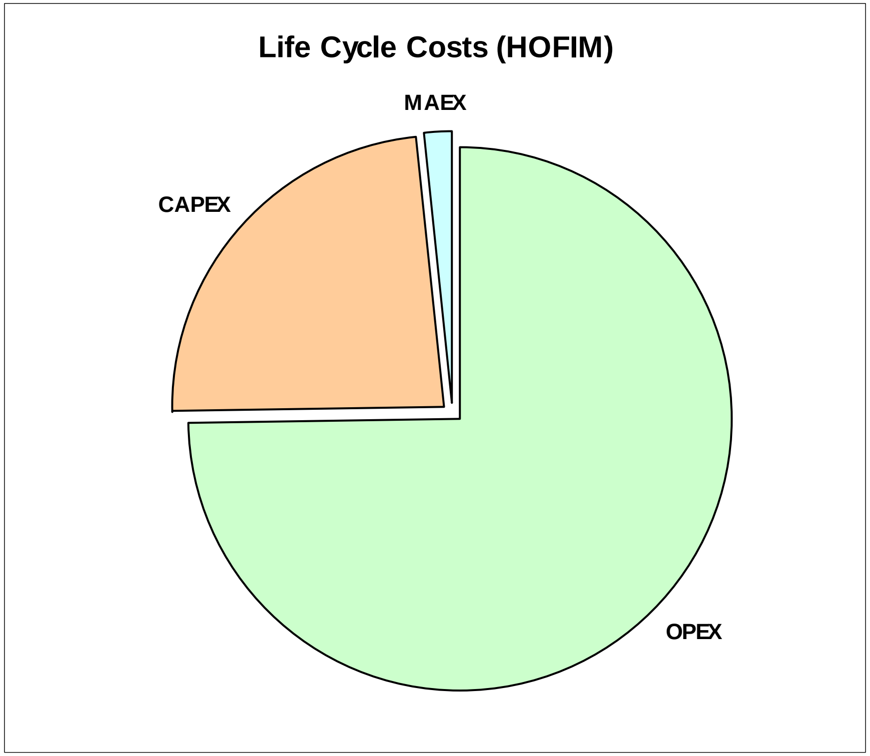
*) only for informative purposes, do not affect the LCC

TOTAL LCCs after utilisation period	**[€]**	**92'330'480**	**91'740'421**	**88'312'551**

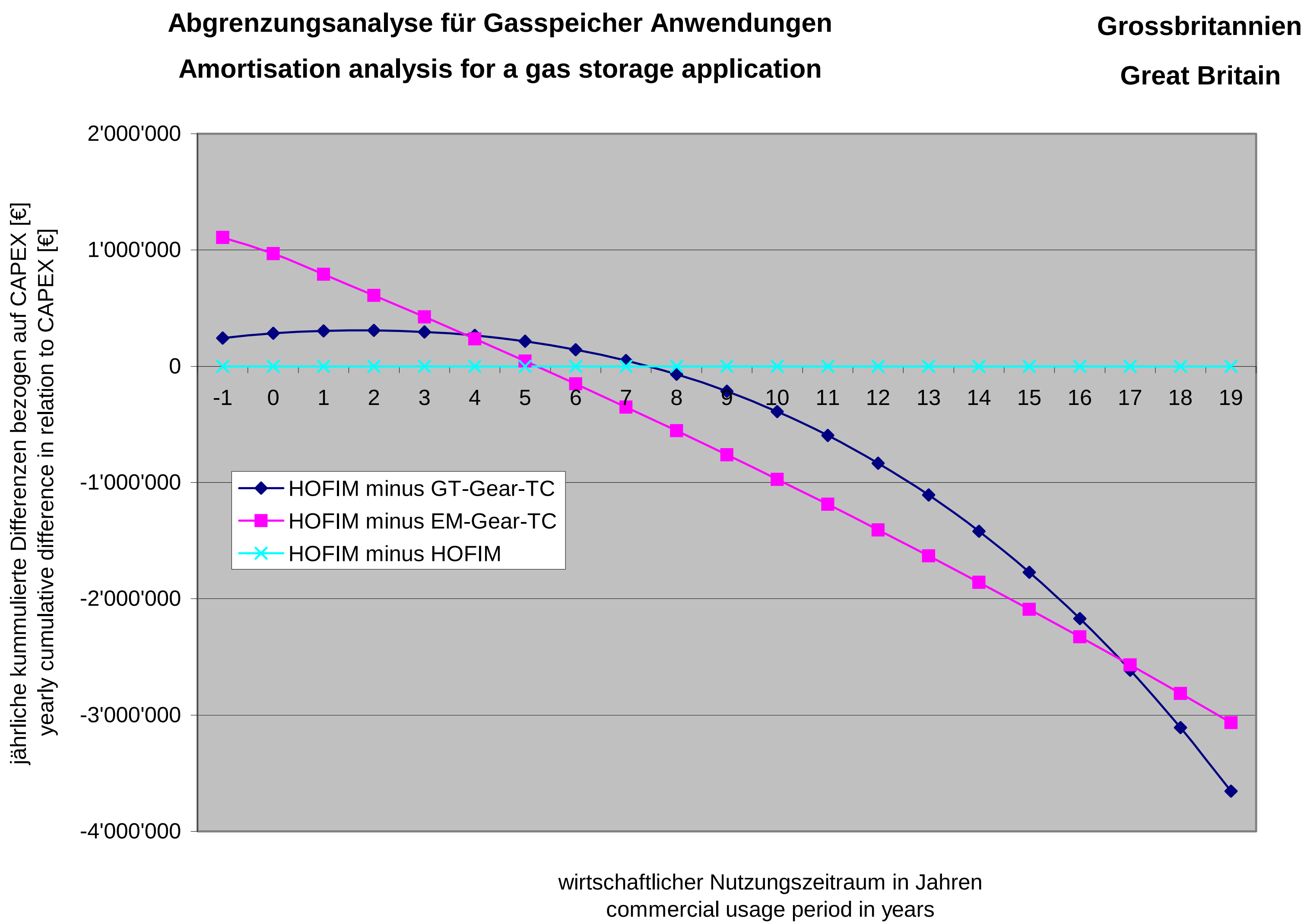
Results on case study

- LCCs are mainly defined through OPEX





Case study: Great Britain



Expected additional emmission costs

Cost of Emissions

- Beside CO_2, other greenhouse gases are involved (CH_4, N_2, HFCs, SF_6)
- Greenhouse effect of methane is approx. 23 times CO_2
- CO_2 – trading already common practice
- Costs of emissions for CH_4 will have to be considered in future (are already considered in several countries)

$$k_{Methan} \approx 23 \times \frac{CO_2}{t} \approx 23 \times Carbix$$

$$K_{Leckage} = \sum_{j=0}^{T-1} m_{K,Leckage} \times t_{Betrieb} \times k_{Methan} \times \left(1 + \frac{i_{Leckage}}{100}\right)^j$$

Conclusion

Electric Compression is of advantage when…..

- a secure and economic source of electric power is available near the compressor station
- capital investment should be as low as possible
- high humidity and ambient temperatures requires derating of the gas turbine
- the electric price/gas price ratio is reasonable
- low-cost night-time energy available for pipeline/storage puffer operation
- environmental restrictions apply (gaseous and noise emission limits, architectural restrictions)
- varying fuel gas qualities or limited transmission capacity in the pipeline exists
- high operating flexibility is required (starting frequency, frequent load cycles, and wide speed range)
- high starting and operating reliability/availability is required
- low operation costs / unmanned operation is required

Conclusion

A general statement cannot be made, because too many project-dependent variables will influence the result. A detailed LCC cost analysis has to be made for each project individually.

- A decision from CAPEX perspective for fuel or electric driven equipment is generally based on the availability of electric power on site, or the cost to bring the power to site.
- If electric power is available at site, the decision going with fuel/electric driven trains is generally OPEX driven (fuel/electric costs)
- Final decision for electric compression or for gas engine driven compresion can only made after considering all project related costs over the life time of the project.

FLEXIBILITY and unknown upcoming future EMMISSION REGULATIONS are the keywords in today's changing gas storage and gas transport business. Electric Compression is preferred to cope with these uncertainties.

Thank you for your attention.

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