Improved drainage boosts CMM to Power economics

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Coal Mine Methane Capture and Use Technologies

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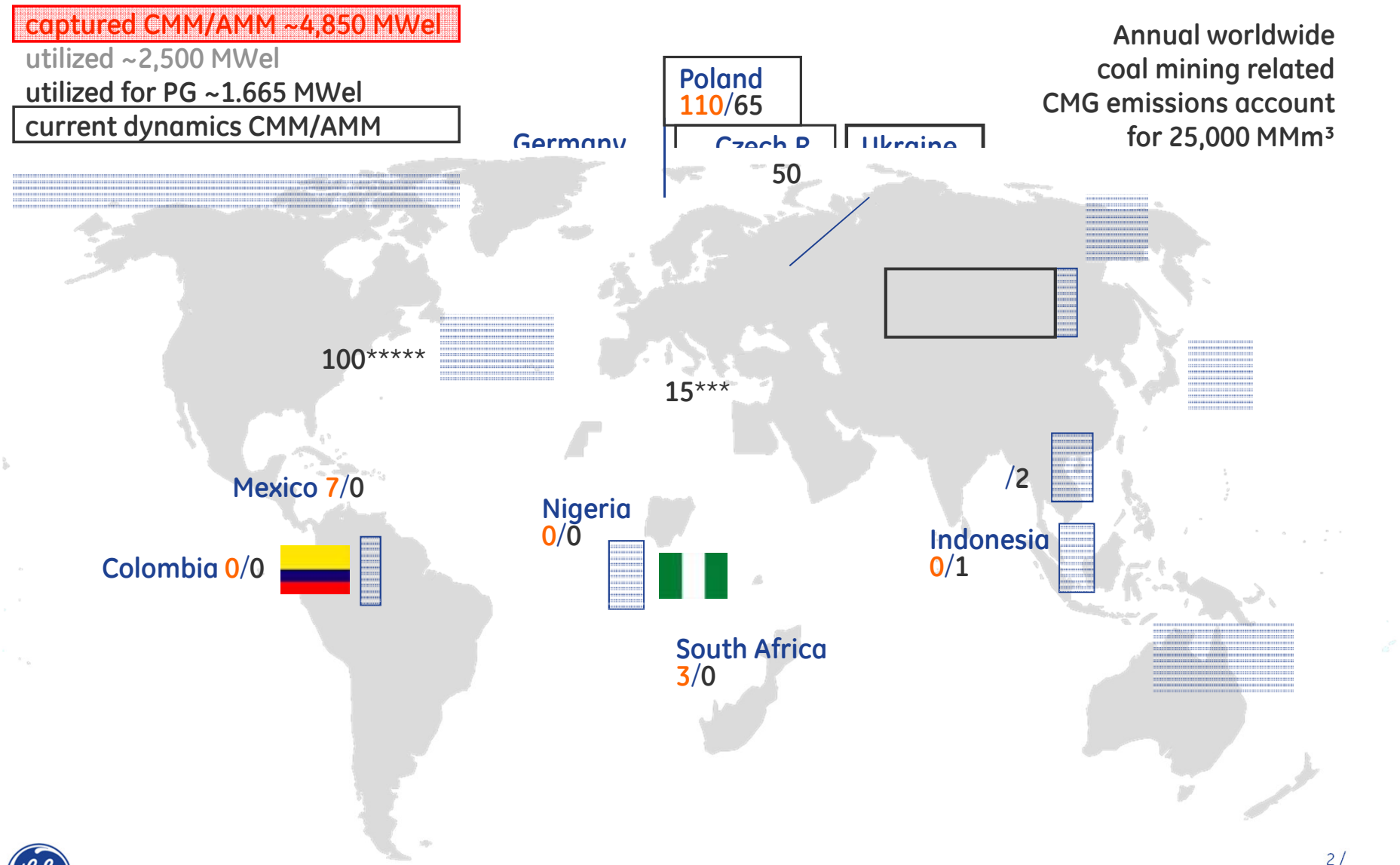
GE imagination at work

Worldwide CMG potential in MWel

captured CMM/AMM ~4,850 MWel
utilized ~2,500 MWel
utilized for PG ~1.665 MWel
current dynamics CMM/AMM

Annual worldwide coal mining related CMG emissions account for 25,000 MMm³



CMG to Energy Business Drivers

Mine Safety: Gas explosions in coal mines still cause severe accidents.

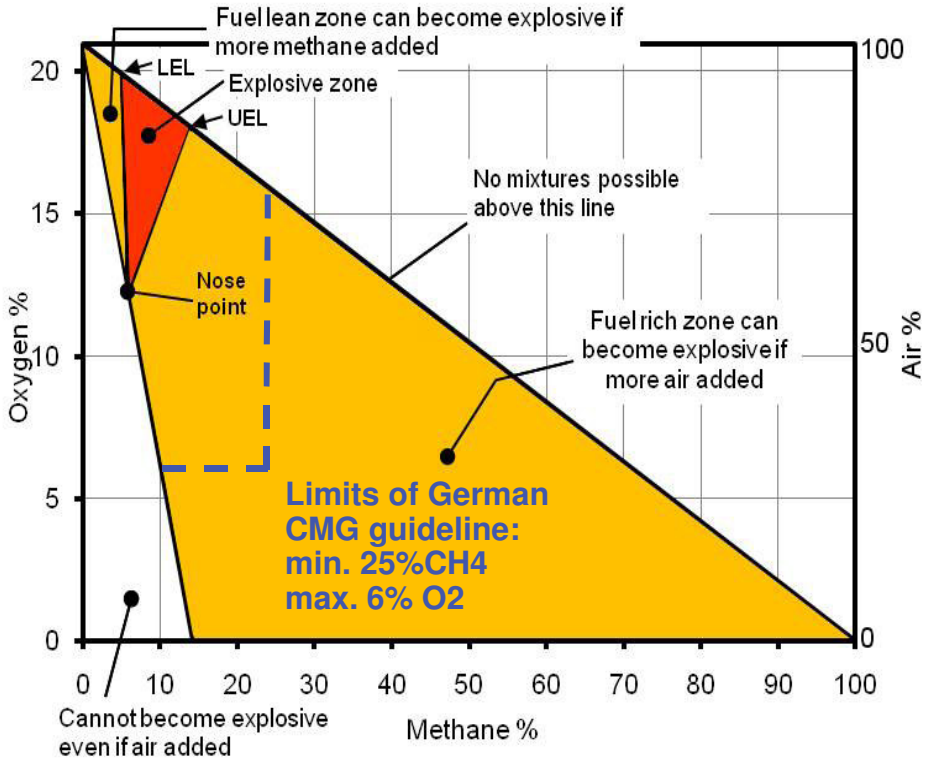
Carbon offset: Trading with carbon credits creates additional revenues besides feed-in tariff.

Coal mine sector restructuring: For many mines CMG to Power helps to establish green image, energy autarchy and business diversity.

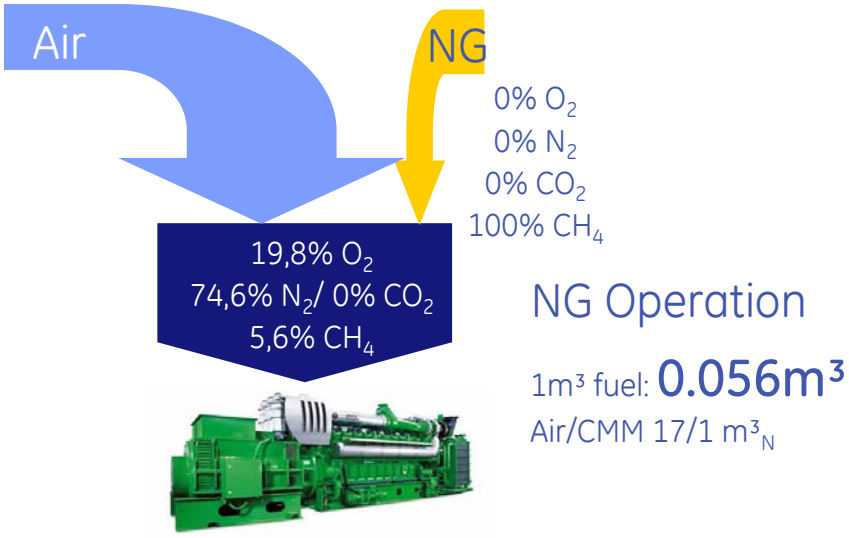
Safety/ productivity aspect of CMM drainage

- Explosive zone 5-15% CH4/air + buffer in case of fluctuations
- > CH4 lower utilization limits 20-30% in most countries
- Surface: Piping, engine, other devices protected by flame arrestors, shut down valve
- Still there is ignitable CMM underground
- Effective gas drainage saves money in the layout of the ventilation system
- Safety aspect is predominant, but coaling productivity will be improved as well

> Independent from CMM utilization, there is a strong business case for installing and operating high efficiency gas drainage systems



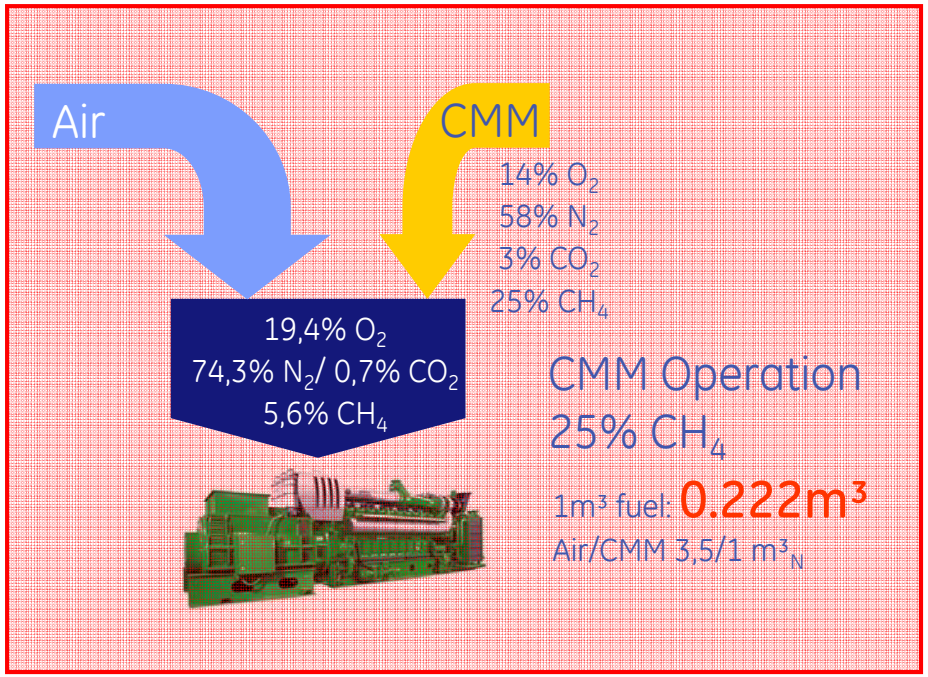
Utilization of low CH4 CMM in gas engines



NG Operation

1m³ fuel: **0.056m³**

Air/CMM 17/1 m^3_N



CMM Operation

25% CH_4

1m³ fuel: **0.222m³**

Air/CMM 3,5/1 m^3_N

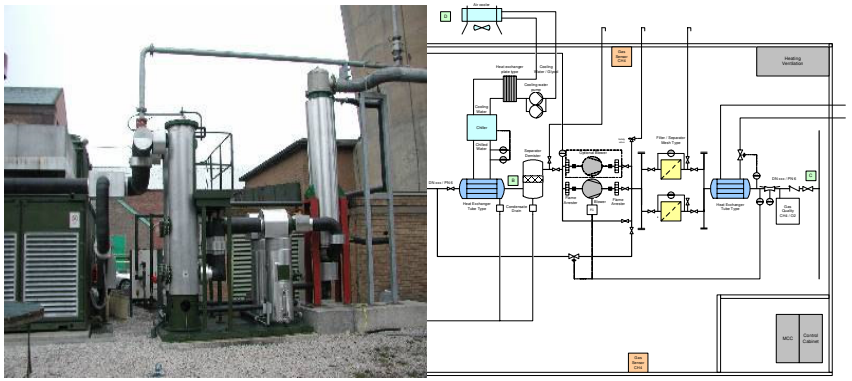
- **Extended gas conditioning**
- **Special gas train lay-out**
- **Special gas mixer**
- Special turbocharger
- Special pre-chamber geometry/ valves
- **Special spark plugs**

> For further decrease of lower utilization limit additional adjustments need to be taken, that will increase gas engine CAPEX and OPEX considerably

Low CH4 CMM Gas Conditioning

Volume
Pressure
Temperature
Humidity
Dust
Impurities

Coal Mine Gas



TA 1000-0301

Engine fuel

Conditioning skid needs to handle multiple times higher gas flows with even higher humidity due to water injection for safety reasons (CHN)

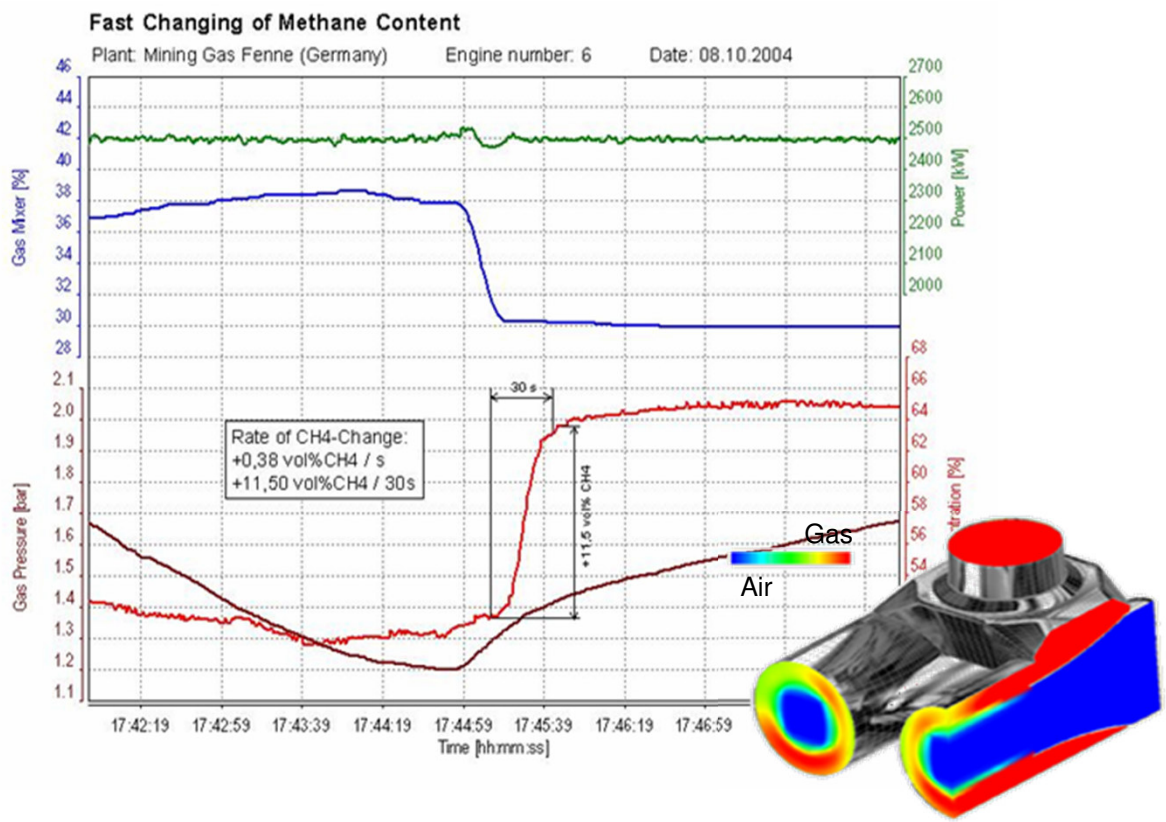
The quality of the gas conditioning has a big influence on the availability of the gas engine

Relative gas train costs/ LHV

Gas type	Gas flow Nm³/h	Pressure	Flame arrestor	Engine adaption	Price
Sewage Gas	1150	80-450	-	2 x 150/16	305%
Sewage Gas	1150	80-450	x	2 x 150/16	396%
Biogas	1660	120-450	-	2 x 150/16	304%
Biogas	1660	120-450	x	2 x 150/16	395%
Biogas	1660	80-450	-	2 x 150/16	449%
Biogas	1660	80-450	x	2 x 150/16	541%
LFG	1980	80-450	-	2 x 150/16	547%
LFG	1980	80-450	x	2 x 150/16	636%
LFG	1980	120 -450	-	2 x 150/16	449%
LFG	1980	120 -450	x	2 x 150/16	541%
CMG	**3150**	**120 450**	**x**	**2 x 150/16**	**839%**
CMG (F)	**2400**	**200 450**	**x**	**2 x 100/16**	**469%**
NG	800	80-450	-	100/16	114%
NG	800	120 -450	-	100/16	103%
NG	800	2 - 4 bar	-	100/16	100%
NG (F)	850	80-450	-	100/16	186%
NG (F)	850	120-450	-	100/16	110%
NG (F)	853	250-550	-	100/16	137%
NG (F)	853	380-1000	-	100/16	137%
NG (F)	850	2 - 4 bar	-	100/16	95%
NG (F)	850	3 - 8 bar	-	100/16	97%

Investment in gas train for very low LHV fuel can become extremely high because of exponentially growing material demand and small batch sizes

Fast Changing CH_4 Content

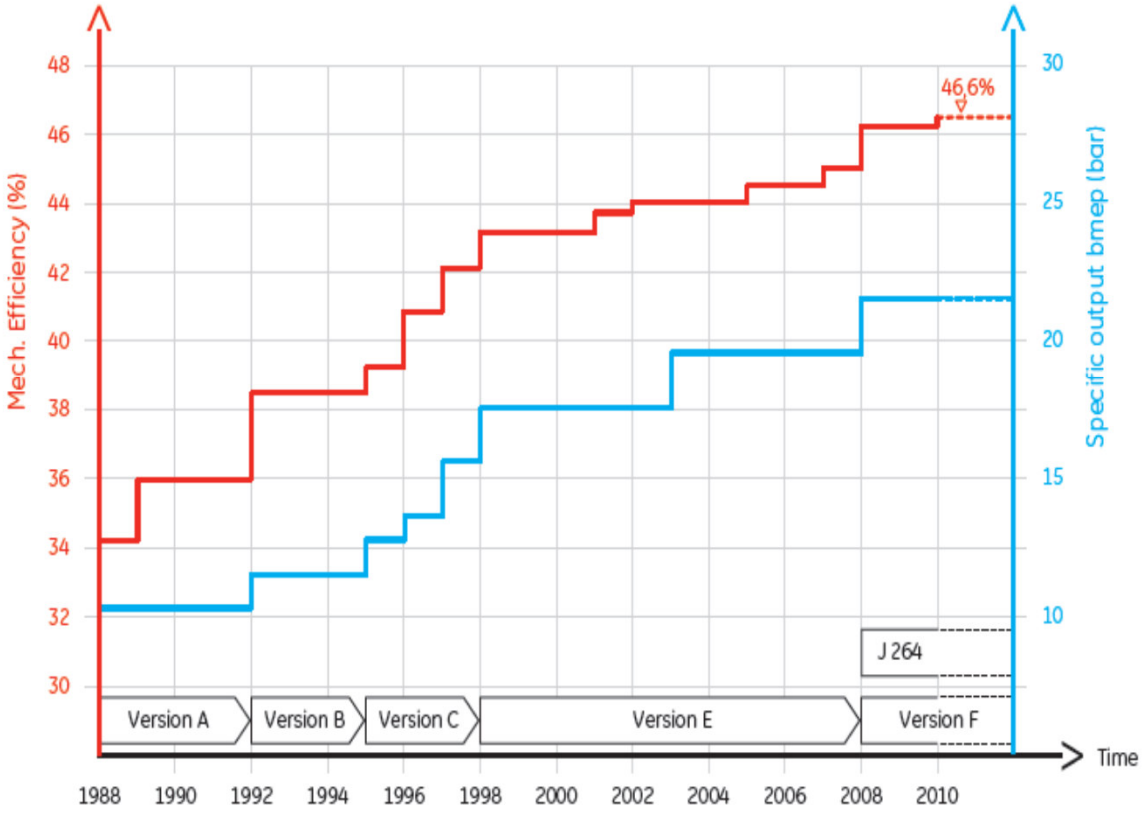


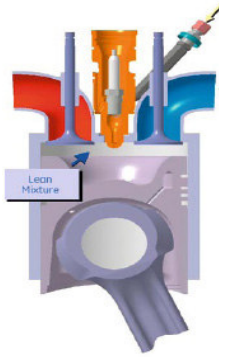
Facts

- CH_4-Concentration is changing faster than **11.5Vol%/30s**
- Only small Load Fluctuation – Engine operation is still stable
- *LEANOX* control system
- Fast Reaction of Gas Mixer
- Longtime experience with turbo charger bypass system

Optimal compensation of CH_4 fluctuation to increase gas engine availability and save gas supply investment becomes harder the lower the average CH_4 level.
Relative LHV decrease is much higher from lower outset level.
From 64 to 52.5% CH4 = -18%, from e.g. 28 to 16.5% CH4 = -41%!!

BMEP/Efficiency development – type 6





CMG achievements

> Electrical efficiency only slightly below NG operation and considerable higher than in open chamber concept

> Spare parts costs at the same level or even lower than with NG

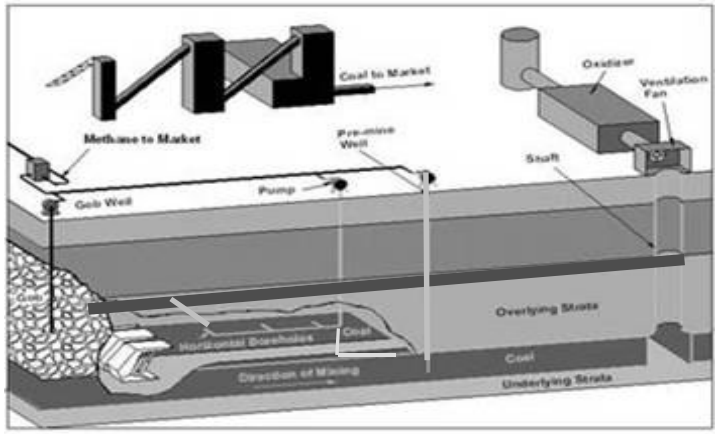
- Proven specific output increase of >100% over 2 decades
- Proven efficiency increase of ~30% over 2 decades

Bring your Coal Mine Gas to a good quality!

Only Coal Mine Gas with a CH4 concentration of at least 30% ...

- improves mine safety through better gas drainage
- saves investment into ventilation system and improves coaling productivity
- complies to official utilization guidelines from local authorities
- will still provide an usable fuel for PG even if CH4 content decreases with time
- safes money in the piping, gas conditioning, gas train and specific engine investment
- eases the cooperation with western technology partners
- ensures an optimal and schedulable carbon credit generation

> Thus your ROI will be finally clearly higher, than developing the project with low CH4 gas concentration



Thank you for your attention!

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