IASS Study Proposal

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17 February 2013

A Methane/Electricity ePipe Infrastructure to Socio-economically and Enviro-responsibly service the Emerging Energy Needs of the European Union

The Global Energy Challenge

- An expanding global population aspiring to the energy-consumption standard of living existing in Europe and North America and and targeted by the emerging societies of middle and western Asia, the Indian subcontinent, Africa and South America.
- Possible adverse climate impact arising from the combustion products of increased amounts of fossil fuels consumed in pursuit of their objective.
- Limited ability to address such needs via renewable energy alternatives and associated physical and political constraints, e.g., the socio-eco-invasive impact imposed by widespread deployment of solar, wind, and bio-sourced generation.
- Vast reserves of natural gas have been uncovered worldwide, and attendant cost-effective retrieval technologies developed for their exploitation. A number of economic imperatives are certain to drive that exploitation worldwide (*See US-EIA 2011 Report: World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States, available here*).
- It is essential such exploitation of our planet's methane reserves be carried out in as environmentally, socio-economic responsible manner as possible, both regarding extraction, transmission and end use, and likewise consideration of candidate replacement technologies 3-4 decades in the future.

One Approach to Fulfillment:
The Methane/Electricity ePipe

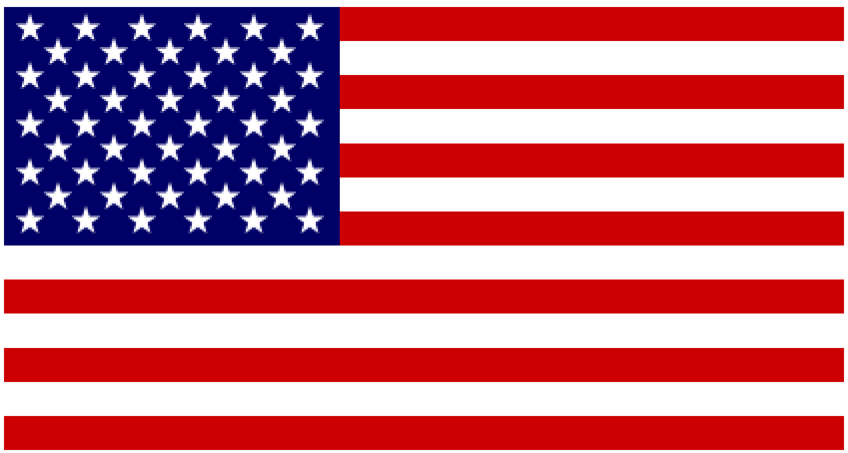
(Nota Bene: "The Fine Print")

- Dual-Use of a common right-of-way (ROW) to co-transport natural gas (methane) and electricity.
- Electricity component to be generated at the gas field wellhead via 50% Carnot-efficient combined cycle turbine technology (CCGT), possibly employing superconducting stator/rotor designs.
- Capture CCGT H_2O & CO_2 exhaust and transform, using emerging technologies, into basic hydrocarbon resources (methanol, ethanol, propanol...) for application in the chemical and medical enterprises.
- Transport wellhead generated electricity via high current capacity "high temperature" superconducting cables (HTSC):
  - ...in a "common" cable carrying cryogenic liquid methane and electricity over LN_2 cooled HTSC.
  - ...or...in two separate embodiments sharing a common ROW:
    - A conventional, but of "advanced design," high pressure gas or LNG pipeline.
    - An HTSC cable comprised of either:
      - Present successful and proven cuprate-based "wires/tapes/cables" refrigerated by liquid nitrogen, or..
      - MgB_2 "wire/cables" refrigerated by an appropriate mixture of gaseous He and H_2.
- Commence planning for eventual depletion of global methane reserves by 2050 and insertion of new generation technologies at the wellhead "footprint" to utilize the now-pre-existing chemical/electrical thoroughfares:
  - Electricity Generation: Advanced clean, safe and renewable/recycleable nuclear fission plants based on essentially inexhaustible supplies of thorium ore...e.g., the Energy Amplifier (latest here).
  - Chemical Generation : Replace methane chemical resources with hydrogen generated electrolytically from H_2O (there are issues...click here), and distribute over existing upgraded natural gas pipelines/
  - Transmission: Insertion in existing ROW upgraded HTSC cables utilizing MgB_2 + liquid H_2 cryogens.

Proposed Study Scope

- Review past "power corridor dual-use studies" in the US
  - J. R. Bartlit, F. J. Edeskuty and E. F. Hammel, "Multiple Use of Cryogenic Fluid Transmission Lines," Proc. ICEC4, Eindhoven, 24/26 May 1972. pdf
  - S. M. Schoenung, W. V. Hassenzahl and P. M. Grant, "System Study of Long Distance Low Voltage Transmission Using High Temperature Superconducting Cable," EPRI Report WO8065-12, March, 1997. pdf
  - P. M. Grant, 'The SuperCable: Dual Delivery of Chemical and Electric Power," IEEE Trans. Appl. Supercon. 15, 1810 – 1813 (2005). pdf
- Gather/Accumulate data to examine possible EU opportunities
  - Research current plans/policies to extend existing, and deploy future, natural gas pipeline infrastructure throughout the European Union and its neighbors.
  - "Imagineer" specific scenarios to insert similar dual-use projects on the North American model onto the European scene.
  - One such scenario, but by no means unique, would be to consider a 1440 km "ePipe" from the Lublin gas fields in eastern Poland through Berlin to Brussels, as is addressed briefly in this proposal.
  - However, the study would survey all opportunities from the highlands of Scotland through Scandinavia to western Russia, southward to the Balkans, westward to Spain and northward to the English Channel (aka, la Manche).

Past/Present Dreams (US-Canada)



I. Multiple Use of Cryogenic Fluid Transmission Lines

J. R. Bartlit, F. J. Edeskuty and E. F. Hammel, "Multiple Use of Cryogenic Fluid Transmission Lines," Proc. ICEC4, Eindhoven, 24/26 May 1972. pdf

A multi-use energy transportation line is envisaged which derives environmental and economic advantages by concurrently transporting liquified natural gas, liquid hydrogen and electricity conducted along either cryogenic (20 K) or superconducting (4 K) cables. Operating parameters are given for a potential application of a 600-mile pipeline carrying gas and electricity flowing from New Mexico to Los Angeles, California, and liquid hydrogen hydrogen flowing from Los Angeles to New Mexico for use in the space shuttle program. Estimated flow-rates, pipe sizes, pressure and voltage losses, heat leaks and refrigeration requirements are given and compared with losses incurred in conventional transmission.

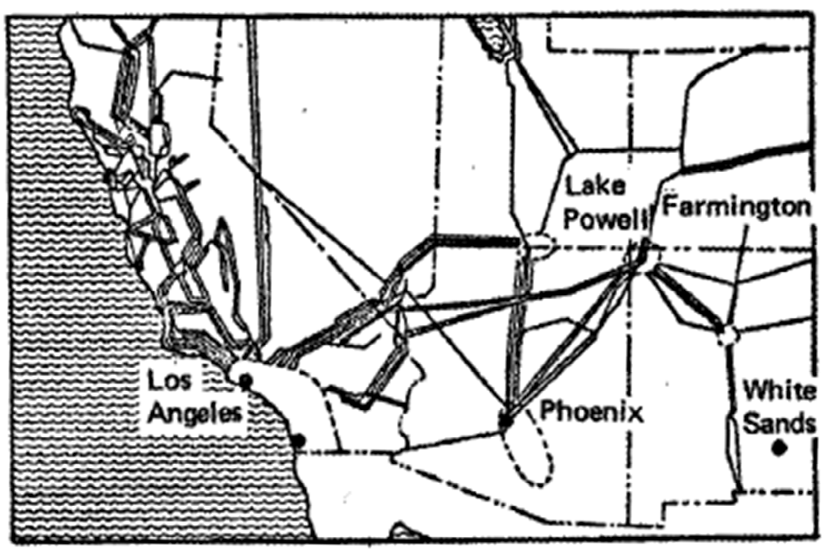


Fig.1 230 kV transmission lines (1990)

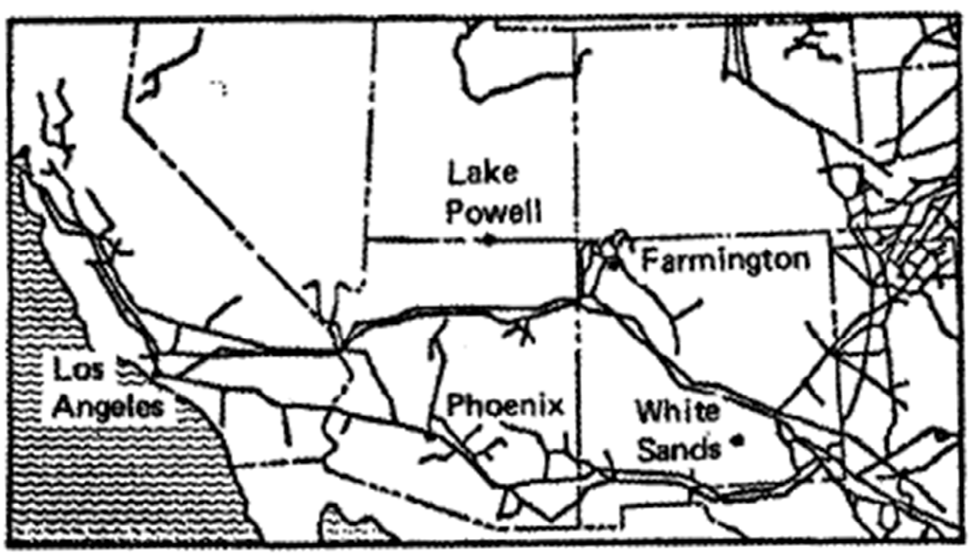


Fig.2 Existing natural gas lines

I. (a)

Table 1

Energy form and/or refrigerant	Case A_1 — separate transfer lines, conventional electricity			Case B — multi-use transfer line, cryoresistive electricity			Case C — multi-use transfer line, superconducting electricity			
	LNG	LH_2	Electricity	LNG	LH_2	Electricity	LNG	LH_2	LHe	Electricity
Temperature (K)	110	20	300	110	20	20	110	20	4	4
Potential (atm or kV)	68	20	2.3×10^5	68	20	2.3×10^5	68	20	3	2.3×10^5
Flow-rate (g/sec or A)	8.0×10^4	2500	4350	8.0×10^4	2500	4350	8.0×10^4	2500	0.056	4350
Flow-rate of useful energy (MW)	4740	350	1000	4740	350	1000	4740	350	0	1000
Pipe size (cm):										
inner diameter	41	15	–	41	15	15	41	15	0.5	0.5
wall thickness	1.2	0.2	–	1.2	0.2	0.2	1.2	0.2	0.13	0.13
Pressure drop (atm/30 km)	6.3	5.1	–	6.3	5.1	–	6.3	5.1	0.08	–
Heat leakage (kW/30 km)	82.5	31	~2200	134	5.4	~2.2	134	4.1	0.00084	~0
Power required for refrigeration (kW/30 km)	463	1710	–	752	355	–	752	283	3.4	–
Pumping power (kW/30 km)	173	26.7	–	173	26.7	–	173	26.7	4.9×10^{-6}	–

II. System Study of Long Distance Low Voltage Transmission Using an HTSC Cable*

S. M. Schoenung, W. V. Hassenzahl and P. M. Grant, EPRI Report WO8065-12, March, 1997. pdf

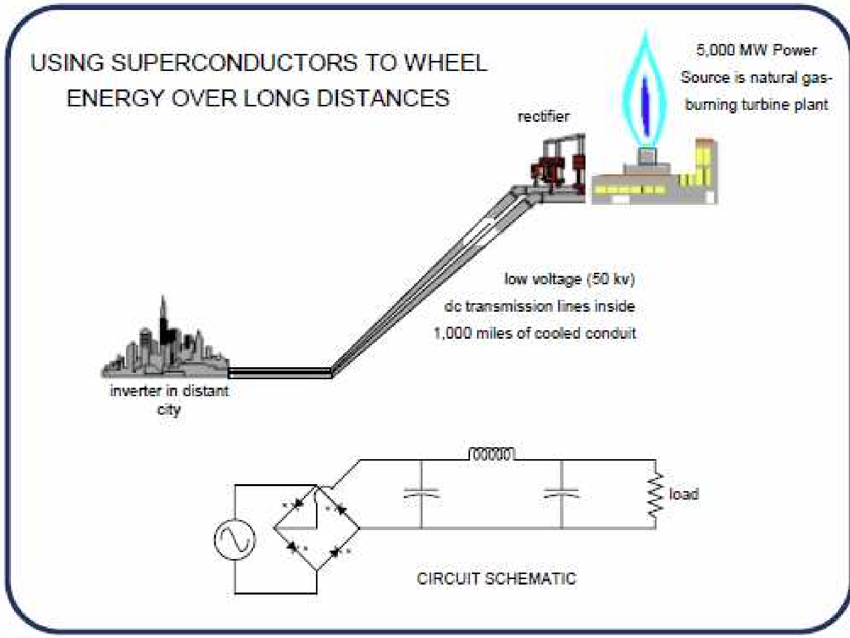
High temperature superconductors (HTS) offer a potential opportunity for long distance transmission of electricity at relatively low voltage. An HTS transmission line could be less expensive than high voltage dc transmission (HVDC) because of reduced convertor costs and lower line losses.

This preliminary analysis of an HTS low voltage dc transmission system suggests that such a system could be economically competitive with both HVDC and gas pipeline transport of bulk energy over long distances. The largest single cost item is the superconducting layer. If this can be provided at a cost around $5/kA-m at the selected operating temperature, then the system is an attractive option.

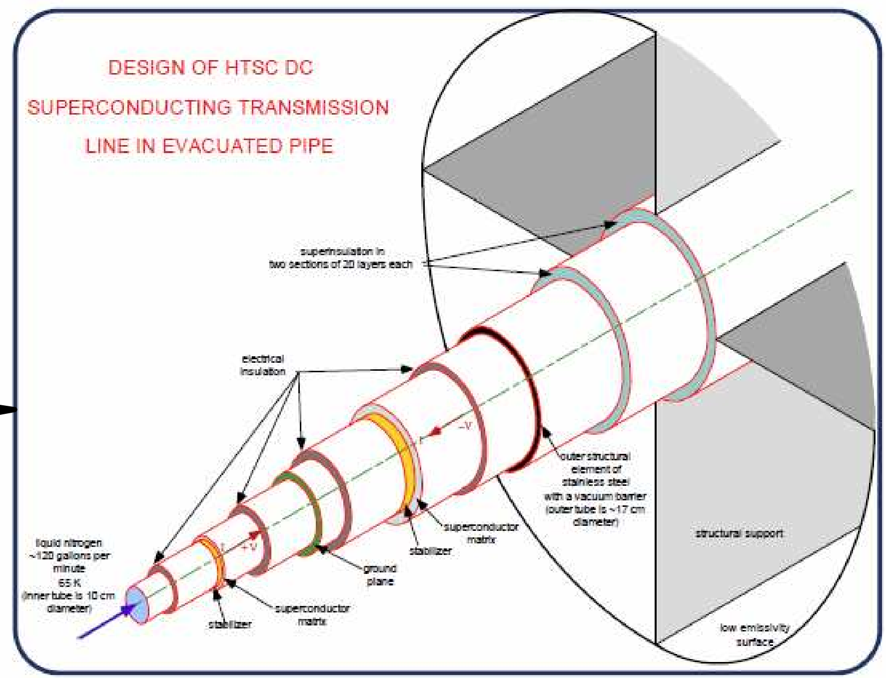
The cost of delivered electricity (¢/kWh) is strongly dependent on the cost of fuel at the source. The trade-off between systems is impacted most by capital costs and parasitic requirements.

**This is an extraordinarily thorough engineering/economy examination of almost all aspects of the "dual use common corridor for methane/electricity co-transport." It was never published and exists solely in the form of an EPRI report here.*

II. (a)



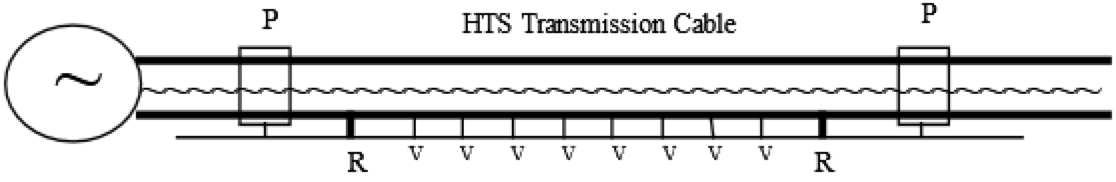
Generic ePipe Layout



Generic ePipe Design

II. (b)


CYPRUS
Nicosia
Mediterranean Sea
SYRIA
Latakia
Hims
Beirut
LEBANON
Damascus
Haifa
ISRAEL
Jerusalem
Gaza Strip
Amman
JORDAN
Al 'Aqabah
Mosul
Karkūk
Baghdad
IRAQ
Al Hillah
Al Kūt
An Nāşiriyah
Al Başrah
Tehrān
Qom
Bākhtarān
Arak
Dezful
Ahvāz
Ābādān
KUWAIT
Kuwait
Bandar-e Būshehr
Alexandria
Cairo
EGYPT
Luxor
Aswān
Tabūk
Hafar al Bāţin
Ha'il
Persian Gulf
Dhahran
Manama
QATAR
Riyadh
Medina
SAUDI ARABIA
Yanbu' al Bahr
Tropic of Cancer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HTS Transmission Cable
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II. (c)

(Con Cuidado: *as of 1997!*)

Cost Assumptions for HVDC Transmission Line and High Capacity Gas Pipelines

Component	**Unit Cost**	**Source**
HVDC Line	$1M / mile	1, 10
HV convertors	$100 / kW	1, 10
Steady state losses	8%	1
HVDC Fixed O&M	2% of installed cost/yr	
HVDC Variable O&M	0.15 ¢/kWh	1, 12
Gas Pipeline	$1.2 M / mile each x 2 lines	1, 13
Compressor power required	5000 HP / 100 mile per line	14
Compressor	$131 / HP	14
Gas Pipeline Fixed O&M	2% of installed cost/yr	
Gas Pipeline Variable O&M	0.15 ¢/kWh	14

III. Cryodelivery Systems for the Cotransmission of Chemical and Electrical Power

The following pages are abstracted from the citation below:

Paul M. Grant, AIP Conf. Proc. 823, 291(2006); doi: 10.1063/1.2202428 pdf

THE LNG HYBRID SUPERCABLE

Realistically, fossil fuels will continue to be exploited for at least three more decades. However, there is underway a major movement away from high carbon content sources as seen by the increasing movement toward natural gas (mostly methane) as witnessed by the fact that some 18% of the electricity generated in the US comes from natural gas-fired turbines, whereas it was almost zero 20 years ago, and is expected to increase dramatically as more restrictions are placed on coal generation. Natural gas production and use in the "lower 48" of the United States has begun to increase faster than new reserves are being discovered and exploited. It is anticipated that much of the future supply to the US will be by tanker transport and offload of liquefied natural gas (LNG) and additional pipelines constructed from the Artic Ocean shelf of North America.

An example of the latter is the Mackenzie Valley Project, a 1220 km, $18 B high capacity pipeline to be built from gas fields in the Mackenzie River delta in the Northwest Territory to existing distribution stations in Alberta, scheduled for completion by 2010. A map of the pipeline route and associated pressurization plants is shown in Figure 5.

III. (a)

FIGURE 5. Route of the projected Mackenzie Valley Pipeline running 1220 km through the Canadian Northwest Territory from the Mackenzie River Delta on the Artic Ocean to northern distribution channels in the province of Alberta [http://www.mackenziegasproject.com]. When completed, the pipeline will convey 1.6 US billion cubic feet per day, the equivalent of 18 GW thermal at the high heat value of methane, approximately that of the electric power capacity of the Three Gorges hydroelectric facility in China.

III. (b)

MVP Specs (NB: *as of 2006!*)

Pipeline Length	1220 km (760 mi)
Diameter	30 in (76 cm)
Gas Pressure	177 atm (2600 psia)
Pressurization Stations	~250 km apart
Flow Velocity	5.3 m/s (12 mph)
Mass Flow	345 kg/s
Volume Flow	1.6 Bcf/d (525 m^3/s)
Power Flow	18 GW (HHV Thermal)
Construction Schedule	2006 - 2010
Employment	25,000
Partners	Esso, APG, C-P, Shell, Exxon
Cost	$ 7.5 B (all private)

III. (c)

Since a significant portion of the natural gas, perhaps as much as 33%, to be eventually transported over the Mackenzie Valley pipeline will be used to generate electricity, let us then consider a possible scenario for future gas pipeline projects which would place the generation plants at the wellhead The electric power thus produced would then be subsequently transmitted, along with liquefied natural gas, in the manner of an LNG SuperCable as envisioned in Figure 6.

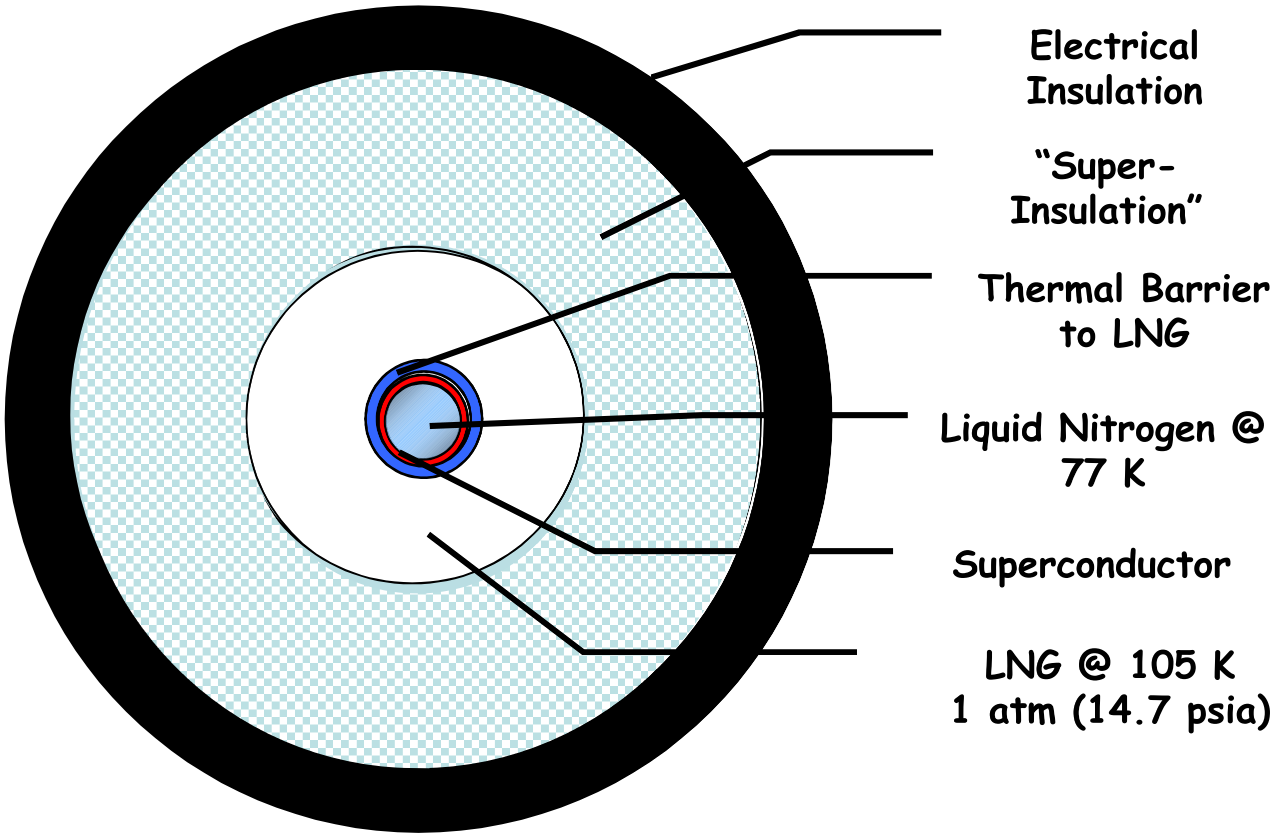


FIGURE 6. Monopole cross-section of a conceptual Liquidfied Natural Gas SuperCable. The cryogen is liquid nitrogen flowing through the center cylindrical tube. Note the presence of a heat shield between the superconductor layer and the LNG channel in order to keep its temperature above 86 K, the freezing point of methane.

III. (d)

Table 4 addresses a scenario using the Mackenzie Valley Project as a template. One – third of the field gas available is diverted to directly generate electricity. The remaining methane is liquefied and it and electricity are “shipped south” on an LNG Hybrid SuperCable. For a standard long distance gas pipeline, re-compression and heating (methane is cooled by expansion as it moves through the pipeline!) stations must be place periodically (100 – 250 km) along its path. For the LNG Hybrid SuperCable, these stations would be replaced by cryogen pumping and refrigeration units.

Should the LNG Hybrid SuperCable model indeed be applied to future exploitation of remote natural gas fields similar to those of the Mackenzie River Delta, when those reserves become exhausted, their very remoteness would make suitable locations for the construction of high temperature gas cooled nuclear reactors capable of both hydrogen and electricity generation with the product shipped on the former LNG SuperCable appropriately converted to carry hydricity.

III. (e)

TABLE 4. Wellhead electricity generation scenario via combined cycle gas turbine generators located on the gas fields of the Mackenzie River Delta delivered over an LNG SuperCable running along the route of the proposed Mackenzie Valley Pipeline.

NB: *Data as of 2006!*

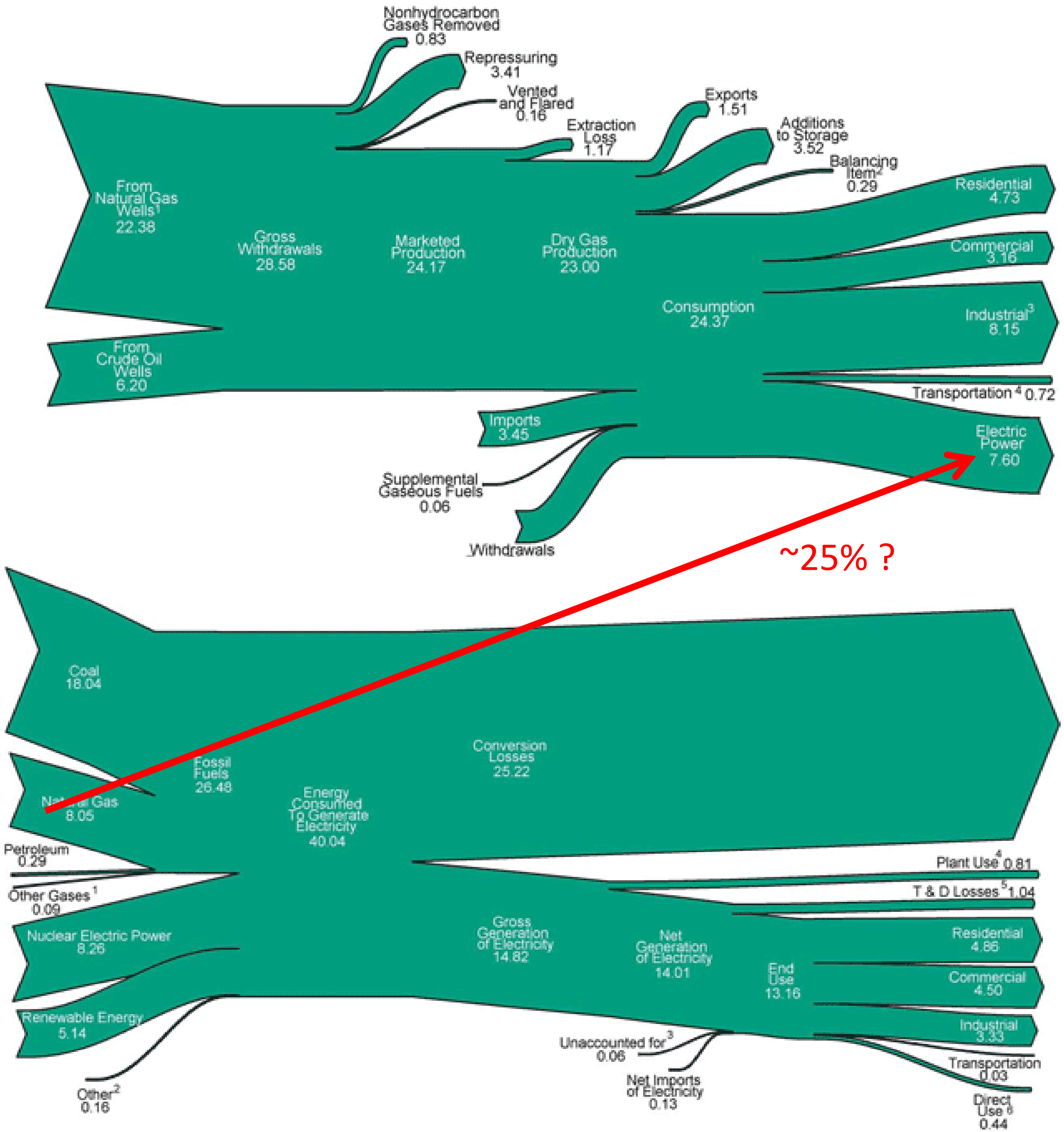
Electricity Conversion Assumptions

Wellhead Power Capacity	18 GW (HHV)
Fraction Making Electricity	33%
Thermal Power Consumed	6 GW (HHV)
Left to Transmit as LNG	12 GW (HHV)
CCGT Efficiency	60%
Electricity Output	3.6 GW (+/- 18 kV, 100 kA)

SuperCable Parameters for LNG Transport

CH_4 Mass Flow (12 GW (HHV))	230 kg/s @ 5.3 m/s
LNG Density (100 K)	440 kg/m^3
LNG Volume Flow	0.53 m^3/s @ 5.3 m/s
Effective Pipe Cross-section	0.1 m^2
Effective Pipe Diameter	0.35 m (14 in)

Other Regional Opportunities? (EU)



US Natural Gas Generation/End Use – 2011

Units = 10^{12} ft^3

= 1.35×10^4 Twh

What/where are the equivalent data for the EU?

US Electricity Generation/End Use – 2011

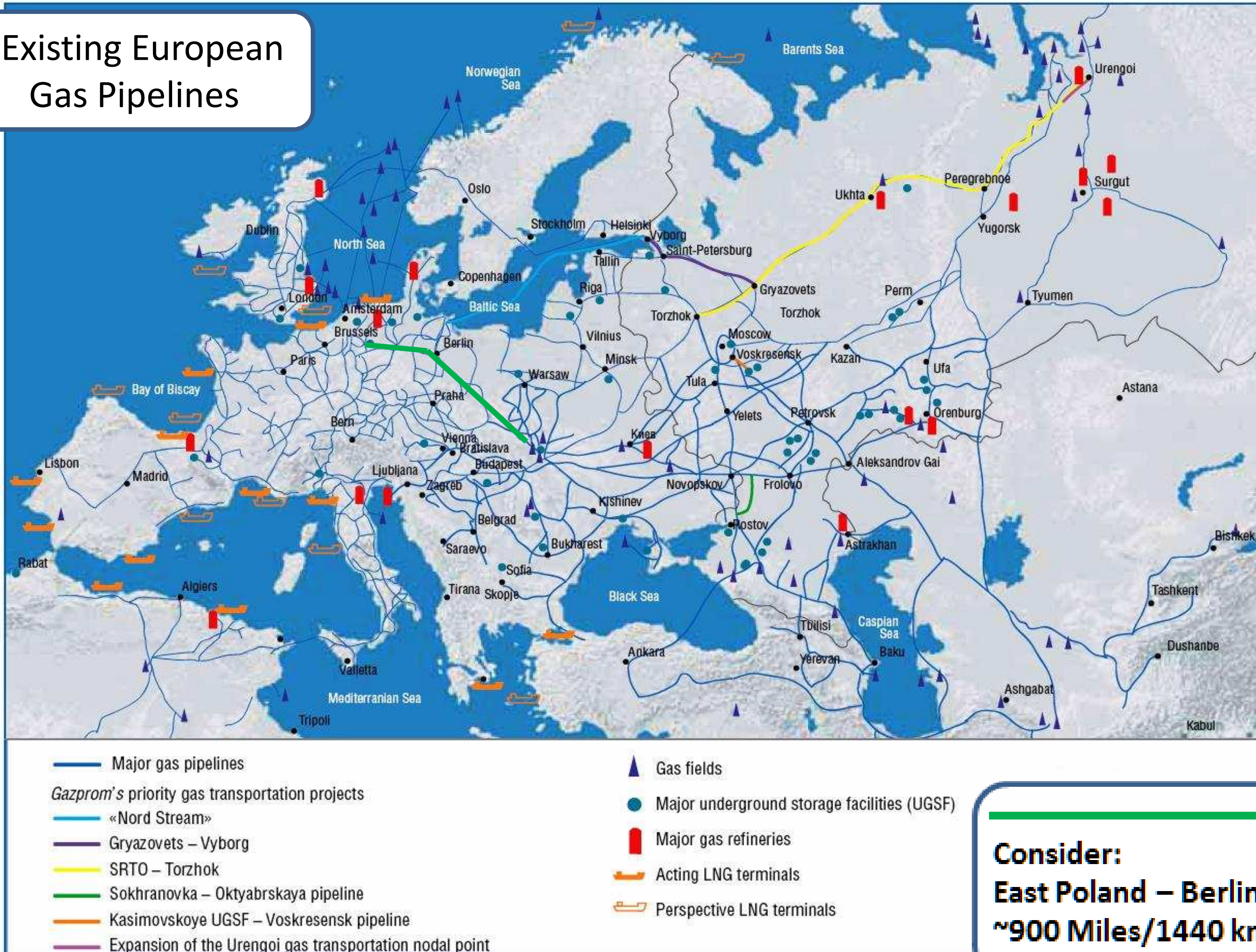
Units = 10^{15} BTU

= 2.933×10^3 Twh

One Possible Scenario (an EU Mackenzie Valley?)

From Where? Poland! ..... To Where? Brussels!

Existing European Gas Pipelines

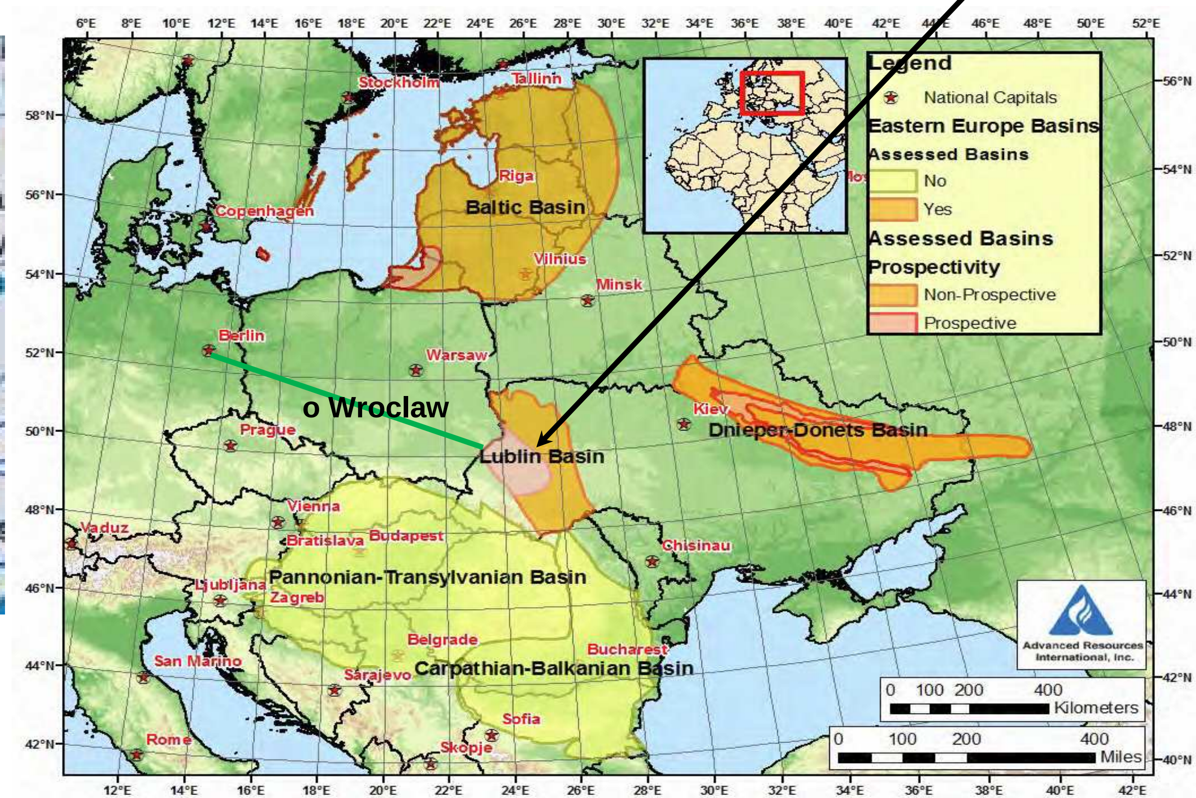


Consider:
East Poland – Berlin – Brussels
~900 Miles/1440 km

Details

The Wola Obszańska* (Lublin) gas field in Poland was discovered in 1989. It began production in 1992 and produces natural gas. The total proven reserves of the Wola Obszańska gas field are around 37 billion cubic feet ($1\times10^9 m^3$).

*https://en.wikipedia.org/wiki/Wola_Obsza%C5%84ska_gas_field



On Site Development

1) Allocate immediate resources to implement advanced IASS technology to recover methanol/ethanol from CCGT H_2O, CO_2 emissions.
2) Allocate future siting areas to implement recycleable, reprocessable thorium-based fission technology along with hydrogen generation.

”Polish-Pipe-Dream” vs. North American & MVP Numbers (Natural Gas Delivery Statistics...Sources/Comparisons)*

Sources	Reserves 10^9 cu·ft	Reserves Twh	wrt US	wrt MVP
US Total	28,600	$3.86 \cdot 10^5$	-	-
MVP	7060	$9.34 \cdot 10^4$	25%	-
Lublin**	37	$5.00 \cdot 10^2$	0.13%	0.52%

Lublin – Berlin Pipeline Corridor “electrons/CH_4 Energy Delivery ePipe Split”

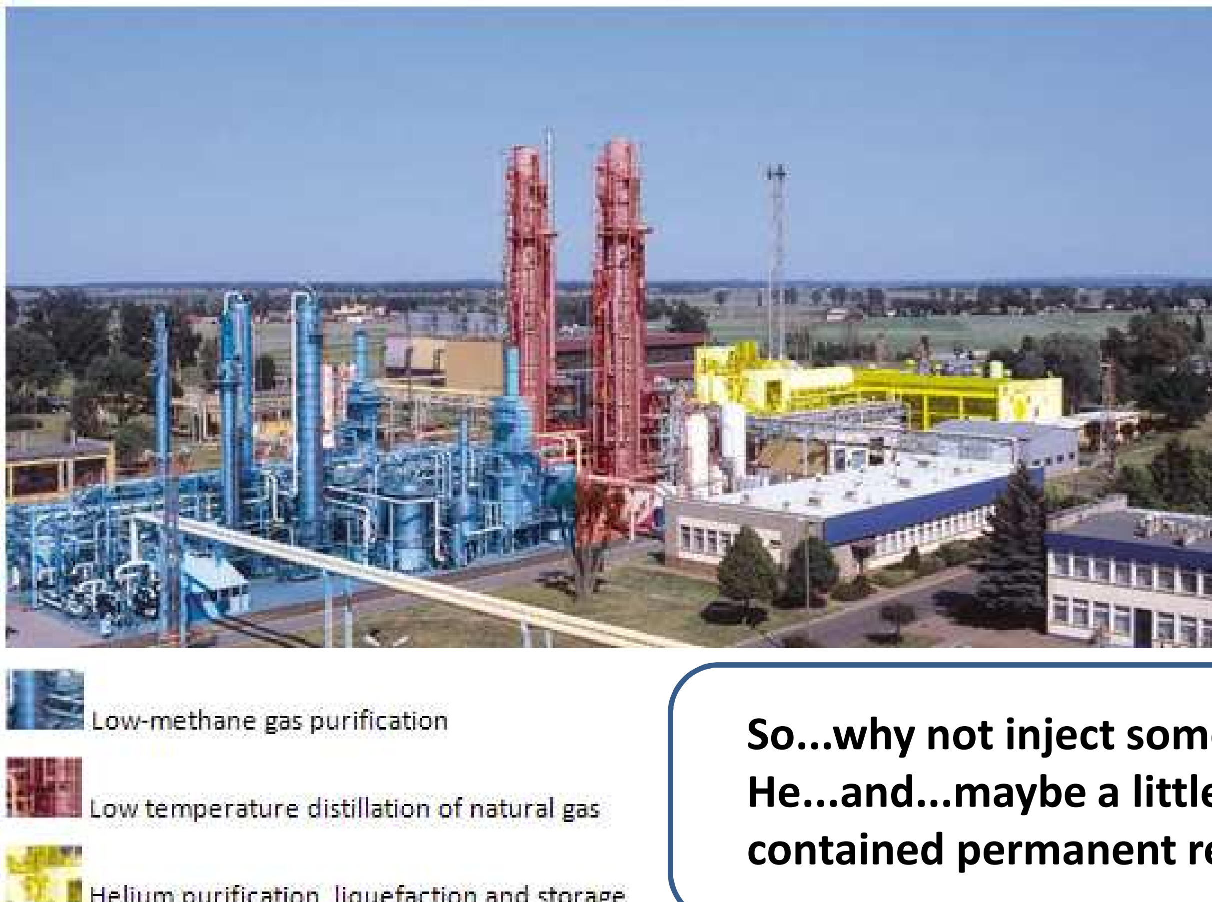
Total Delivered Power (GW)	CH_4 Portion (GW)	“electrons” Portion (GW)***	CCGT efficiency – 50% (GW)	Years Until Exhaustion**
2.5	1.0	1.0	0.5	22.3

*US-DOE-EIA: http://www.eia.gov/analysis/studies/worldshalegas/ Table I (note only proven reserves data are used, not possible recoverable shale deposits).
**https://en.wikipedia.org/wiki/Wola_Obsza%C5%84ska_gas_field (if nearby Ukrainian are available provable reserves were to be included, perhaps 5 times this number could be realized).
***See EPRI Report WO8065-12, March, 1997 (pdf), EPRI Report 1020458 (pdf), for possible HTSC cable designs.

Oh...BTW...along the way, there's...

Krio Odolanow

A hundred kilometres to the north-east of Wroclaw there is KRIO Odolanów, the branch of Polish Oil and Gas Company, which operates the only installation in Europe for **helium recovery** from natural gas. The technology utilized in KRIO Odolanów is based on cryogenic processes and its two main products are liquid helium and liquefied natural gas.



So...why not inject some He...and...maybe a little H_2...as self-contained permanent refrigerants?

Proposed IASS ePipe Study Focus Topics

- Design of HTSC Cable, Finances, Infrastructure – Support Resources
  - EPRI Report WO8065-12, March, 1997. pdf
  - AIP Conf. Proc. 823, 291(2006); doi: 10.1063/1.2202428 pdf
  - EPRI Report 1020458, pdf
- Satisfaction of EU socio-economic energy delivery objectives, especially near-term CO_2 recovery/reuse
- Mid-21st century replacement of depleted methane reserves by advanced, environmentally respectful, nuclear fission alternatives to deliver electrons and protons (H^+) throughout the EU

The IASS ePipe "Dream Team"

- Organizers/Coordinators
  - Paul Grant (in residence)
  - Steve Eckroad
- Selected IASS Staff*
- Consulting Support
  - William Hassenzahl, AdvEnergy
  - Nexans/Columbus
  - BASF
  - PGNiG
  - Gazprom
  - Naftogaz
  - Fermilab/CERN
  - Selected EU university/MPI expertise
  - Selected EU/German government agency relevant staff
- Study Team Report Due
  - Mid-Summer 2013

*To include C. Rubbia, of course