International Renewable Hydrogen Transmission Demonstration Facility (IRHTDF)

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Abstract

Wind is the lowest-cost renewable energy source, but the largest and richest "deposits", including the Russian Far East and the Great Plains of North America, are stranded, without means for gathering and transmitting the energy to distant markets. Earth's richest biomass and direct-insolation resources are also stranded. We will need many large new transmission systems for gathering and delivering Earth's vast, diverse, dispersed, renewable energy resources. Both high voltage direct current (HVDC) electricity and gaseous hydrogen (GH2) pipeline are attractive, complementary, and competitive.

Pipelining GH2 costs ~1.3 - 1.8 times more than natural gas (NG). New NG transmission pipeline systems may be built with line pipe capable of 100% GH2, for future conversion to "renewables-hydrogen service" (RHS) at up to 100% GH2, to bring energy from windpower, biomass and other distant renewable sources to market as, and after, the NG is depleted. Since well-constructed and well-maintained pipelines have very long service lives, any increased investment required for construction with RHS-capable line pipe may be justified. These pipeline systems may be retrofitted with compressors, meters, valves and other fittings necessary for future RHS, for the nascent "renewables-hydrogen economy".

Although industry has been safely pipelining GH2 for decades, these systems are not designed for frequently-varying pressure and for large-scale, long-distance, cross-country collection, as required by RHS. No pipelines for such service exist. The public is unfamiliar with hydrogen (H_2) and anxious about its safety. Thus, a new pilot-scale R&D and demonstration pipeline system, an International Renewable Hydrogen Transmission Demonstration Facility (IRHTDF), is needed to demonstrate technical and economic feasibility of RHS. We describe and offer a conceptual design for the IRHTDF, which might be an ideal project for the International Partnership for the Hydrogen Economy (IPHE). [1]

Keywords: transmission pipeline, renewable-source, windpower, pilot-scale, stranded, IPHE

1. Introduction

We propose that the international H_2 community starts immediately to design and build a pilot-scale H_2 pipeline system that would collect energy from diverse renewable sources, such as wind and biomass, and transport it cross-country to a small community or a university campus where it would be used for vehicle and distributed-generation fuel. This would be an international, renewable-source hydrogen, transmission demonstration facility (IRHTDF). International collaboration on preliminary design would lead to an RFP for final design, construction, and operation.

Designing and building it would require us to confront and solve a variety of technical, economic, and social challenges. Its successful operation will allow us to estimate the cost of H_2 fuel, delivered to major markets, from large-scale gathering and long-distance transmission of stranded renewable sources. This cost will guide public and private policy and resource allocation among the various H_2 sources in a sustainable "hydrogen component" of our nascent global energy economy.

Transmission pipelines are very complex and costly systems that must be optimized, from sources to end uses, for net present value, NPV. Some reject a GH2 energy sector as too inefficient. [2] RMI's Amory Lovins and Germany's LBST respond. [3], [4] We need empirical results from IRHTDF to reveal synergies and resolve this efficiency-vs-cost conflict. Meantime, the EC, via Gasunie Research and the "Naturalhy Project", will "… test all the critical components of a full hydrogen system by adding hydrogen to natural gas in existing [pipeline] networks" . [5]

2. Launching the renewables-hydrogen sector

We should launch the renewables-hydrogen energy sector of a carbon-emissions-free global energy economy now, fueling ICE-hybrid vehicles until fuel cells are widely available. Renewables are ready. Windpower now costs US 4 – 5 cents per kWh, unsubsidized, at the plant gate, at a good wind resource; perhaps US 3 cents long-term, at large scale. But, much of the world's richest wind resources are stranded. We will need to build many large, new transmission systems to bring it to distant markets. The wind resources of the twelve Great Plains states of the USA, if fully harvested annually, would equal the entire energy consumption of the USA in year 2002, about 10,000 TWh.

Delivering all Great Plains wind energy as electricity would require about 900 of the largest-practical new electric transmission lines: 3,000 MW, HVDC, +/- 600 kv. Fossil generation would be displaced, and H_2 fuel could then be made, at or near point-of-use, from electricity by large or small electrolyzers. At large scale, electric distribution systems must be enlarged to bring this new energy to "distributed generation" (DG) in large or small electrolyzers.

Alternatively, we could deliver all this wind energy as compressed H_2 gas, via about 400 new GH2 pipelines, 36" diameter, ~ 7 MPa. GH2 pipelines provide valuable energy storage, which electricity transmission cannot. New underground GH2 pipelines might be easier to site and permit than large, new overhead electric transmission lines. H_2 fuel from large pipeline terminals would be distributed via tube trailers and low-pressure pipelines.

3. Gaseous hydrogen (GH2) pipelines

An NREL study [6] shows that, at large-scale (> 1 GW) and long distance (> 500 km), gas pipeline is the lowest-cost way to transport H_2. See Figure 1. Although industry has been safely pipelining H_2 for decades, no pipeline system has been designed and optimized for large-scale, long-distance, cross-country transmission of diverse, dispersed, time-varying renewable sources, at minimum cost, and providing energy storage.

The capital, O+M, and transmission loss costs of large electricity and GH2 pipeline systems are comparable: at ~ 1,200 km delivered wind energy cost is twice plant-gate cost.
Pipelining GH2 at large scale will cost ~ 1.3 – 1.8 times more than pipelining natural gas, per unit energy, because:

1) GH2 volumetric energy density is only one-third that of NG;
2) H_2 attack on steel ("hydrogen embrittlement") must be prevented;
3) Compressors, meters, valves, fittings are more costly.

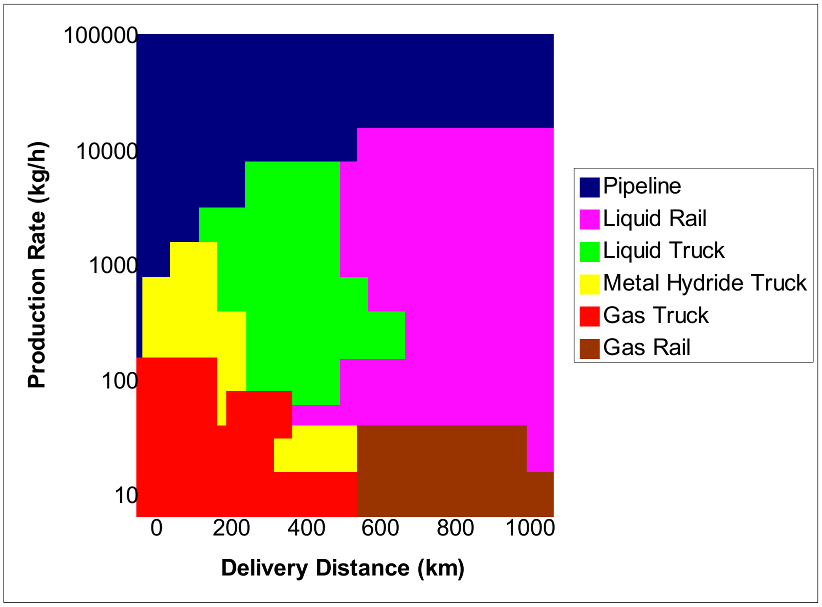

Figure 1. Cost of transporting H_2. [6] Gas pipeline (blue) is the lowest-cost H_2 transmission path at high-capacity and long-distance. Approximate capacity of 12" pipeline @ 7 MPa = 10,000 kg/hr = 240 tons per day = 400 MW. Approximate capacity of 36" pipeline @ 7 MPa = 100,000 kg/hr = 2,400 tons per day = 4,000 MW.

But, GH2 pipeline transmission adds important value to renewable-source energy:
1) Energy storage in the pipeline;
2) Byproduct oxygen from electrolysis is available for dry biomass gasification;
3) Seasonal resource variability is complemented;
4) Small sources may deliver to the pipeline, via simple and low-cost "on ramps".

We must both minimize the costs and enhance the benefits of GH2 pipelining if large-scale stranded renewable energy sources are to be brought to market at competitive prices.

We must discover and demonstrate what these costs and synergistic benefits will be, for H_2 from large-scale, distant, diverse, diffuse, dispersed renewable energy sources, whose output varies widely at hourly to seasonal time scales. We can then estimate the long-term cost of H_2 delivered to load centers for vehicle and distributed generation (DG) fuel, to guide policy and resource allocation among the several salient methods of H_2 generation.

Electricity transmission for large-scale stranded renewables is a mature, available, and economical alternative to GH2 pipelines. But new electric transmission lines are difficult to site and permit; pipelines may be easier. Pipelines provide significant energy storage; electric lines do not. [7]

4. New NG pipelines may be GH2-capable, for RHS

Japan, Russia, China, and others plan a very large new NG transmission pipeline system in the Russian Far East. [8],[9] See Figures 2, 3. Japan asks (a) whether it should be built of hydrogen-capable line pipe, so that GH2 may be added to the natural gas from diverse renewable sources all along the route, finally to 100% H_2; (b) what line pipe is suitable;

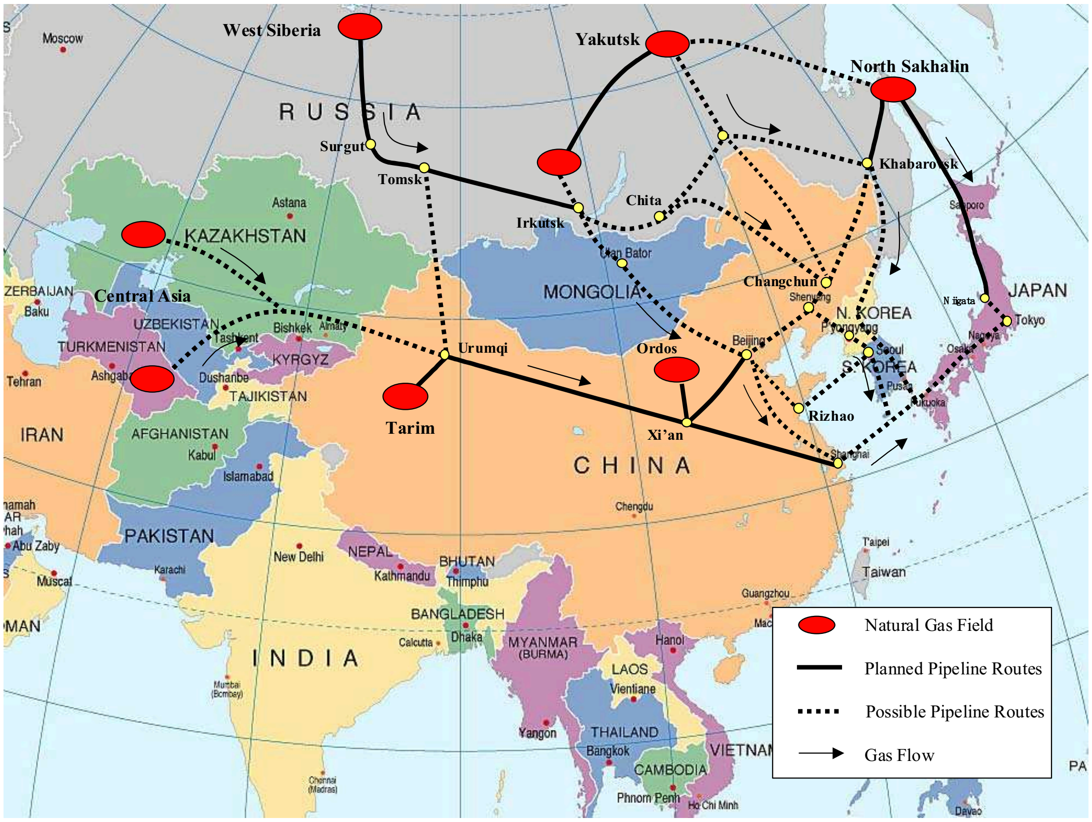

Figure 2. Northeast Asia Natural Gas Pipeline Network, Proposed by Northeast Asia Natural Gas & Pipeline Forum in 2000, which might be built of GH2-capable line pipe for RHS.

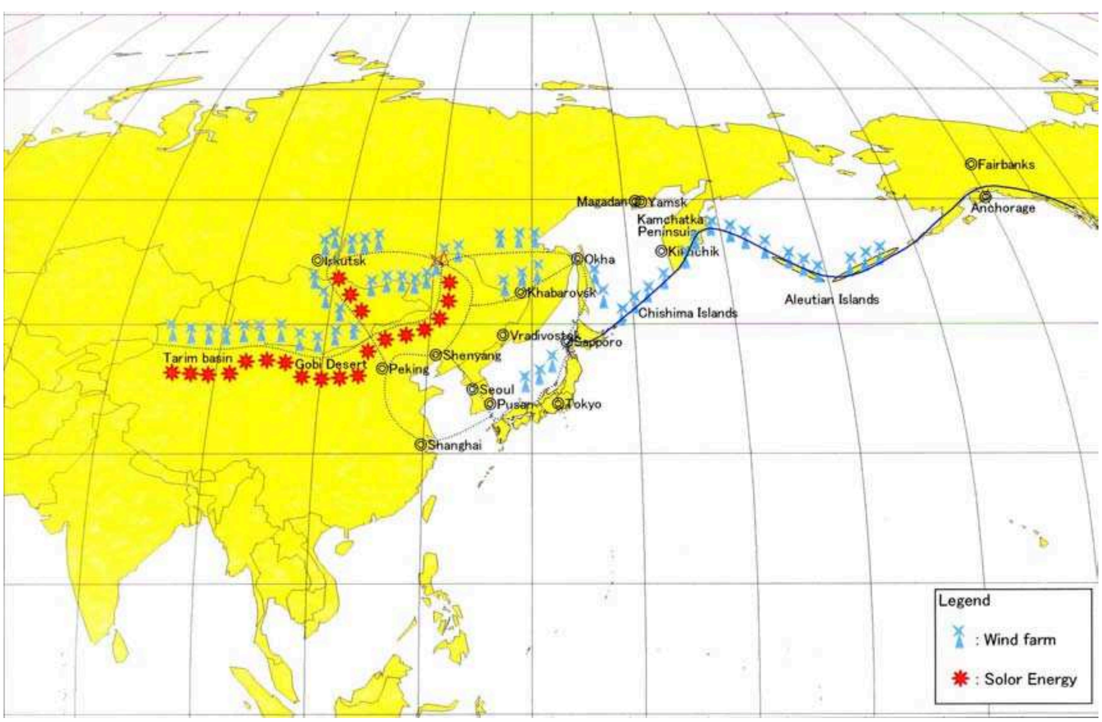

Figure 3. Future large-scale renewable energy sources deliver GH2 to a new, hydrogen-capable, NG gathering and transmission pipeline system.

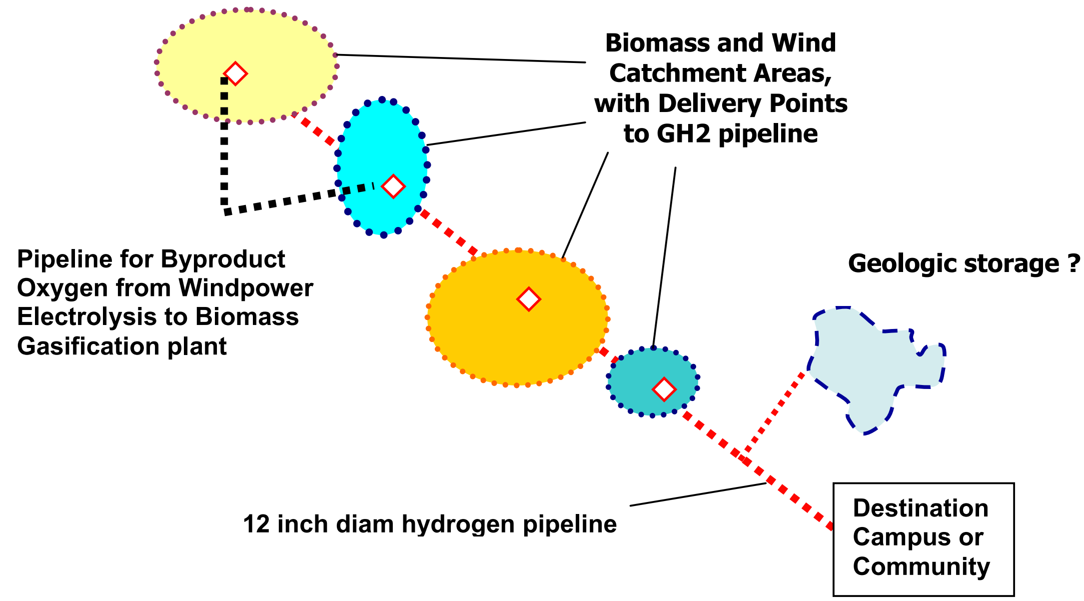

Figure 4. IRHTDF is not only a pipeline, but a corridor of synergistic renewable energy generation, conversion, transmission, storage, and utilization, plus utilization of the oxygen byproduct of electrolysis.

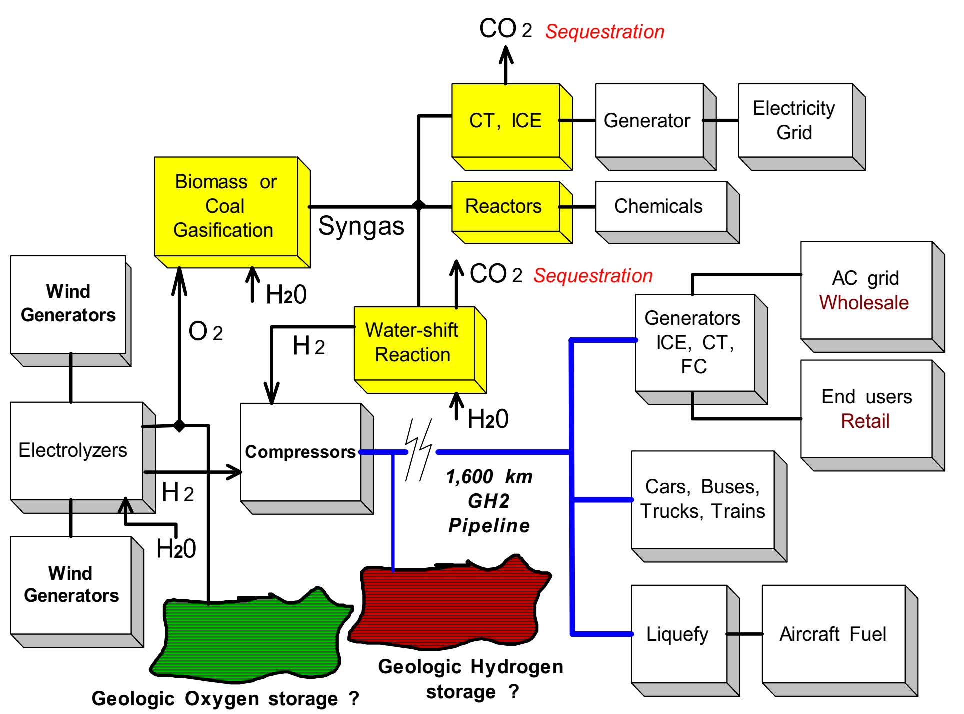

Figure 5. IRHTDF advanced system with potential biomass and "near zero emissions" biomass or coal gasification synergy, using oxygen (O_2) byproduct of electrolysis. Feasibility of large-scale geologic storage of H_2 and O_2 in the USA Great Plains is unknown.

(c) what is the incremental capital cost for this capability for 100% H_2 transmission from diverse, distributed, time-varying renewable sources? Should all new NG pipelines, globally, be designed and constructed as GH2-compatible? The initial incremental investment in line pipe oversized in diameter and pressure capability for NG service may be difficult to justify; it represents excess, unused capacity during the period of NG service.

5. IRHTDF concept: a pilot-scale GH2 pipeline system

See Figures 4 and 5, which emphasize system design, and technical and economic synergy.
1) 12" diam pipeline: >100 MW capacity, for easy pigging inspection and energy storage;
2) 30 – 100 km long, cross-country through public and private land;
3) > 10 MPa; capable of 2:1 pressure cycling at daily time scale without H**2**-attack damage;
4) 100% GH2 from multiple, diverse sources and sizes: wind, biomass, etc.;
5) Optimized to demonstrate GH2 generation, gathering, transmission, storage, distribution.

IRHTDF embraces several opportunities, problems, and hypotheses at once:
1) Renewable-source H_2 can make a major contribution, in both short and long term;
2) GH2 can be transported long distance, at large scale, economically and safely;
3) Large scale energy storage can firm renewables, by:
    a. Integrating energy harvest over very large catchment areas;
    b. Stockpiling biomass feedstocks;
    c. Perhaps storing GH2 in geologic formations at very large, seasonal scale.
4) Synergy among diverse renewable sources of a wide range generation capacity;
5) Synergistic use of oxygen byproduct of electrolysis for dry biomass gasification;
6) We needn't wait for fuel cell cars, "Nextgen" coal, and HTGR nuclear plants to launch a limited "hydrogen economy" now with renewables and H_2-fueled-ICE-hybrid vehicles;
7) New, large, electric transmission lines will be costly and controversial; GH2 pipelines may be the better way to bring large-scale stranded renewables to markets.

IRHTDF is an international research and demonstration facility:
1) Worldwide application to large stranded renewable resources; consistent with IPHE;
2) Open, non-proprietary results from R+D and demonstration;
3) ~100 MW, 30 – 100 km, >12" diameter, >100 bar GH2 pipeline;
4) Many diverse sources and many users along the pipeline system right-of-way;
5) Develop credible cost models; pipelining GH2 is more costly than pipelining NG.

The capital cost of the IRHTDF might be $US 50 million, plus precursor planning, design, and research, suggesting an international effort. The next step is to compose a credible and attractive RFP for design, construction, and perhaps long-term management of the IRHTDF.

5.1. Candidate location: Ames, Iowa, USA

Figure 4. A new 12" diameter pipeline, ~ 100 km long, ~ 100 MW capacity, optimized for 100% GH2 service, would be designed and built from west of Fort Dodge, Iowa to Ames, Iowa, home of USDOE Ames Laboratory, Iowa State University (ISU), and Iowa Department of Transportation (IADOT). The pipeline would collect pure GH2 from diverse, dispersed, renewable energy catchment areas and conversion systems -- wind generators, biomass reactors -- to many acceptance points all along pipeline right-of-way. It would deliver GH2 to the ISU campus, for vehicles and stationary fuel cells in combined-heat-and-power (CHP) systems. GH2 fuel could also be delivered to retail public vehicle fueling stations.

6. Renewables-Hydrogen Service (RHS) technical challenges [10]

Renewable energy sources are time-varying at hourly to seasonal scales. Using GH2 transmission pipelines as storage buffers to damp such frequent 2:1 pressure fluctuations will exacerbate H_2 attack on the pipeline steel. Described variously as hydrogen-induced cracking (or corrosion) (HIC), hydrogen corrosion cracking (HCC), stress corrosion cracking (SCC), and hydrogen embrittlement (HE), this fatigue phenomenon has always troubled the oil and gas industry; frequent pipeline inspection and occasional major repairs are necessary. Valves, meters, and compressors are similarly affected. The IRHTDF will motivate novel, economical solutions for preventing and mitigating this H_2 attack danger.

6.1 Composite Reinforced Line Pipe (CRLP ™) for RHS [11]

Figure 6. Composite Reinforced Line Pipe, CRLP™, may be especially attractive for RHS. A high performance composite material reinforces a thin-wall, high strength low alloy steel pipe. The steel and composite work together, creating a hybrid that provides an economical alternative to higher strength all-steel pipe. The composite increases the pressure carrying capacity of the pipeline by reinforcing the steel pipe in the hoop direction, and is an external anti-corrosion coating. In hydrostatic testing the completed pipeline, the correct overpressure is applied to expand and deform the steel liner against the composite, leaving the steel in static compression, the composite in static tension, over the complete pipeline operating pressure range. This maintains hoop strain compatibility, and will help prevent SCC and room temperature creep that may result from long-term cyclic loading. Other benefits:

1) Lower total installed capital cost than all-steel pipe, at large size and high pressure;
2) Low alloy steel liner, which is more weldable and inherently less susceptible to HIC, HE, and SCC; girth welds designed for fatigue resistance; wide choice of liner pipe material;
3) Thin wall steel liner, reducing weight per unit length and welding time;
4) Effective elimination of axial crack propagation by rapid arrest of axial crack growth;
5) Higher burst to operating pressure ratio;

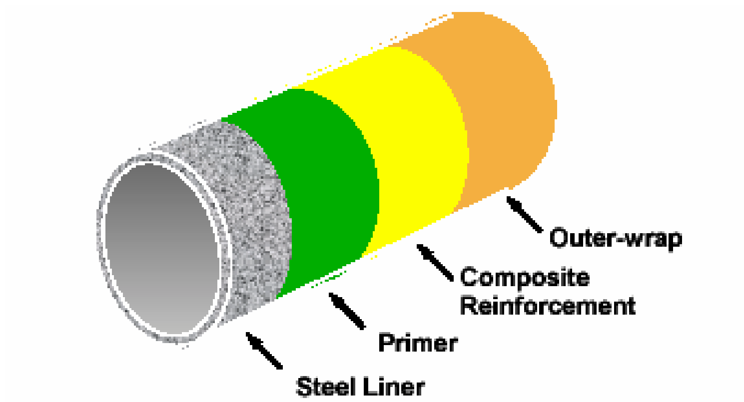

Figure 6. Composite Reinforced Line Pipe (CRLP™).
TransCanada Pipelines, manufactured under license from NCF Industries, Inc. [7]

7. International Partnership for the Hydrogen Economy (IPHE)

The IRHTDF may be an ideal IPHE project, per the 18-21 Nov 03 Ministerial Meeting: [1]
"Goal: To provide a mechanism to efficiently organize, evaluate and coordinate multinational research, development and deployment programs that advance the transition to a global hydrogen economy…. The *Partnership* will provide a mechanism to organize, evaluate and coordinate multinational research, development and deployment programs that advance the transition to a global hydrogen economy… bring together the world's best intellectual skills and talents to solve difficult problems; and develop interoperable technology standards... public-private collaboration [on] technological, financial and institutional barriers to a cost-competitive, standardized, widely accessible, safe and environmentally benign hydrogen economy… advance research, development and deployment of hydrogen production, storage, transport and distribution technologies…foster large-scale, long-term public-private cooperation to advance hydrogen and fuel cell technology and infrastructure development; "

"…important that IPHE be a value-adding proposition for all countries…must be inclusive and offer a good return on investment for all participating countries…" (Australia)
"… large-scale demonstration projects… have the potential to provide the scale necessary for driving down costs and providing clear signals to industry… raise public's awareness of hydrogen's potential and reassure… about its safety…" (Canada)
"…the EC is considering jointly with European industry… large-scale deployment … Lighthouse Projects…" (European Commission)
"…the IPHE should focus on two main objectives: the launch of concrete international cooperation pilot projects, involving the private sector, for the development of technologies that are, at the same time, efficient and economically viable…" (Italy)
"…there is a diversity of views as to what is meant by the hydrogen economy. One size does not fit all…we don't see the hydrogen economy as just about transport… where there is a need to balance intermittent renewables and to store excess capacity…" (UK)

8. Conclusion

Renewables are ready: we propose to begin this pilot-scale demonstration now, fueling ICE-hybrid vehicles. [12] Wind is the lowest-cost renewable; the best wind is stranded; we will need many new transmission systems to bring Great Plains, USA wind, and other large resources, to market. An NREL study shows GH2 pipelines to be the lowest-cost H_2 transmission path at high volume and long distance. We need to learn, now, whether large-scale renewable-source H_2, including conversion and long-distance transmission costs, will be competitive with other H_2 sources, in the long term. Efficient high-pressure-output electrolyzers, and line pipe and other components resistant to hydrogen-embrittlement from severe cyclic loading need to be developed and proven, at MW scale. The IRHTDF is a necessary vehicle and strategy. It may be an ideal IPHE project. One such demonstration is worth many research projects, in popular and policy effect.

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