Hydrogen and Fuel Cell Power – An Alternative Route to Electric Transport for Passengers and Freight?

Herbert Wancura

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NTDA Qualification

- Multiple fuel cell system integration projects including transport applications
  - Hydrogen/Fuel Cell Locomotive
  - Hydrogen/Fuel Cell Power Boat
  - Range Extender Solutions for Battery Electric Vehicles
- Independent Design Capacity and Experience in Refueling Infrastructure
- Multiple Strategic Advisory Projects including Macro-economics and Financing
- Leading Member of the European Industry Grouping and Governing Board Member of the FCH-JTI with the European Commission

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Background (1)

- Urbanization is expected to be one of the continued “Mega-trends” throughout the 21st Century
  - Approx. 50% of the worlds population live in urban agglomerations
  - The UN World Urbanizations Prospects Report expects this number to reach 60% or approx. 5 Bio. people by 2030
    - ⇨ 93% of the growth of (approx. 1.8 Bio. People) will be in developing countries
    - ⇨ 80% will be in Asia and Africa

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Background (2)

- Despite the current slowdown the world economic structure is expected to continue to be strongly dependent on an international division of labor and consequently trade
- This results in significant requirements for transport capacity and infrastructure
- Rail based transport has provided the backbone of much of the industrial age, with the transition from steam-power to two very distinct systems:
  - Diesel and diesel-electric systems particular in USA and Canada mostly dictated by the large distances and relatively low frequency of use, but there are significant environmental penalties
  - Electric (overhead) systems for most of Europe (exception e.g. UK) and Japan

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Background (3)

Diesel Train Emissions In Southern California

Table 1. Year 2000 Main Line Rail Network Emissions from BNSF, UP, Passenger Trains (Emissions Expressed in tons)

Year 2000	ROG	CO	NOx	PM10	SOx
BNSF	238.06	325.76	7235.67	162.88	448.55
UP	253.72	347.20	7711.83	173.60	478.07
Passenger	6.65	48.33	476.60	11.08	31.74
Sum	**498.43**	**721.29**	**15424.10**	**347.56**	**958.36**

[Source: Leachman, 2005]

Table 2. Year 2000 Main Line Rail Network Emssions from Traffic Delay (Emissions Expressed in tons)

Year	ROG	CO	NOx	PM10	SOx
2000	**9.65**	**100.46**	**13.85**	**0.54**	**0.09**

[Source: Leachman, 2005]

This emission is the equivalent of the total of the 350 largest factories and facilities in the Southern California Region!

Source: SCAQMD, cited in R.F.Smith et al: Electrification of the Freight Train network from the Ports of Los Angeles and Long beach to the Inland Empire; final report on Prime Award no. 65ª0244, Subaward No. GT 70770, California Dept. of Transportation; California State Politechnic University, Pomona, May 2008

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Background (4)

- Public Mass Transit was originally largely electric (Trams/Trolleybuses), but subsequently replaced by ICE powered buses, mostly diesel fueled.
- Recently there have been first signs of trend reversals due to:
  - Urban pollution problems
    - (see also various tests with hybrids, CNG, Biogas, Hydrogen etc.)
  - Noise issues
  - Fuel Cost Concerns
- Solutions are a partial revival of electric trolley busses and trams both in the USA and Europe

Issues with Electrification of Transport - Urban Context

- Complex planning process for infrastructure
- High investment cost
  - Example Trolleybus (Prices: Austria, February 2004)
    - 2 track catenary system 0.21 M€/km, **plus**
      - Catenary Support 4k€/unit
      - Catenary crossing 21k€/unit
      - Track Seperator 15k€/unit
      - Feeding point 6k€/unit
      - Electric/mechanical switch gear 75k€/unit
      - Substation 0.43M€/unit
    - Trolleybus vehicle 400k€ (solo), 500k€ (articulated), approx. +100% over a diesel bus
  - Tramways are are even more expensive
    - Infrastructure 3-4.5M€/km (depending on terrain and integration with existing infrastructure)
    - Tramway Rolling Stock approx. 2.0 – 3.5 M€/unit (200-250PAX)
- Visual intrusion
- Limited flexibility in operations due to infrastructure dependency leading to higher cost units (duo power with diesel back-up)

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Issues with Electrification of Transport - Medium/Long Distance Passenger /Freight Rail Context

- Limited scalability of infrastructure
- Limitations of freight traffic due to vertical clearance restrictions (double container, triple automotive container
- Adaptation needs of existing infrastructure, e.g. bridge or tunnel height
- Larger land use requirements due to higher lateral requirements
- Significant investment needs
  - Infrastructure bottleneck situation e.g. single line electrified vs. double track not electrified (Electrification may be as high as 15-18M€/km acc. to SCRRA [R.F. Smith et al., 2008])
  - Rolling stock with higher cost

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Benefits of Electrification

- Broad range of primary energy sources including renewable and indigenous sources
  - Depending on electricity generation mix may also lead to lowering of GHGs
    - Local efficiency of electric powered trains is ~90% versus 48% for diesel
    - Electric Traction adhesion is 35-40% versus <20% for US diesel locomotives [Glenn T. Fisher, 2008]
- In general higher stability of electricity prices than the very volatile light diesel
  - medium and heavy oils long term unsuitable due to pollutant considerations
  - Current discussions of biogas are an improvement but only half the way while incurring significant infrastruture and rolling stock needs
- Significant benefits regarding toxic pollutants in both urban and medium/long distance contexts
- Lowering of noise levels at property line by 30dB(A)

Grid Issues with Electrification

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- In areas with poor electric grid stability large train concentrations may create problems of grid failure [D. van der Meulen, Spoornet, ZA, 2000] which can be both detrimental to
  - General electricity supply quality
  - Train operational safety
- In urban context high electrification may create additional grid load at inopportune times of peak load, e.g. morning and late afternoon (200 Trams correspond to 40-60MWe or 6.000-10.000 households)
- Large scale freight transport or high speed passenger train may dictate grid voltage (minimum voltage 25kV, large freight up to 50kV)

Vision

Large Scale Hydrogen Powered Transport

- Combine the benefits
  - Operational flexibility of diesel
  - Infrastructure impact and visual intrusion reduction
  - Maintain simple scalability
  - Environmental benefits of electric transport
  - Initially higher rolling stock investment is offset by significantly lower infrastructure cost
  - Grid valley utilization for low cost transport energy and grid stabilization

Urban + Interurban Transport (1)

- One-way distance < 100km
  - FCH Busses from 8.5m to 25m
    - Technology comparable to existing FCH-Busses 70-250kWe FC, Hybrid Battery or Supercapacitors, 350 or 700bar CGH2 Storage
    - Transport capacity comparable to existing busses and trams
    - Investment cost of rolling stock comparable to battery busses or standard trams
    - Infrastructure cost reduced to a few H2 production and refueling stations – highly scalable and sharable with other transport users
    - Full operational flexibility in routing etc.
    - For interurban lines possibly with guide-wire driver assist concepts and separated track, reducing driver work load

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Regional Rail (2)

- One Way Distance < 250km
  - FCH Hybrid Regional Trains

    (data extrapolated from [NTDA 2006, E. Agenios et al, 2009])
    - Replacement of diesel or diesel genset units by advanced hybrid FC-technology
    - Peak power rating comparable 250-400kWe per unit in multiple self powered bogey designs
      - 150kWe FC
      - 200kWe peak battery with approx. 300kWh storage
      - 100kWe Supercap
    - Up to 2.5MW peak power incl. hybridization for front end locomotive design for up to 10 rail cars, peak velocity 160km/h
      - Average power use is typically 300kW, this would allow FC to operate in its most efficient area with approx. 55% electric efficiency vs. 36% for the Diesel Gen Set.
      - 500 -800kWe FC system
      - 500kWe peak Battery with approx. 800 kWh storage
      - 1 MW Supercap capacity
    - Hydrogen Storage CGH2 300kg per day, 3500Nm3, 16m3 space requirement

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Long Distance Rail (3)

- Large Scale Long Distance Freight/Passenger Transport
  - One way distances of up to 1000km
  - FCH-HEV Locomotives 18-22m frames
    - Can be equipped with 2-4MWe FC HEV Drives
      - 2MW FC, 1,5MW Battery, 1-1,5 MW Supercaps
      - Space requirement 14-18m3 plus HX areas
      - Electric drive plus Power electronics 8-10m3
    - On-board storage either in LH2 technology (Magna Steyr StorHy Project Result) with a on-board capacity of up to 800kg H2 or 26MWh (or approx. 10 hr running time for 30% duty cycle of 4MW)
      - Space requirement approx. 24m3
    - Total space available on a 20m frame approx. 75m3
  - Requires investment into end point H2 Liquefaction Plants (> 50M€ per unit [*A. Opfermann, Linde AG*]) but break even point may be reached at distances as low as 100km depending on terrain.

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Why do we feel confident?

- Because we did do an in-depth investigation for an industrial client in 2005/2006 (results are confidential)
- Because an internal design update done at the beginning of 2010 regarding the 2005 design shows that we can fit at approx. 3MW of FC capacity in a hybridized system with up to 5.5MW peak power
- Because we think it is a highly attractive option to leapfrog the Diesel/Diesel hybrid to Electricity step
- Because even for modest distances we expect it to be an economical choice
  - In the developing world for reasons of infrastructure and maintenance cost and long term isolation from oil/gas cost including a full renewable energy powered transport chain
  - In Europe as it would give a major chance to benefit from the need to balance the grid (e.g. night valley in Spain 8-100GWh per day wasted wind power resources enough to power 1000trains per day)

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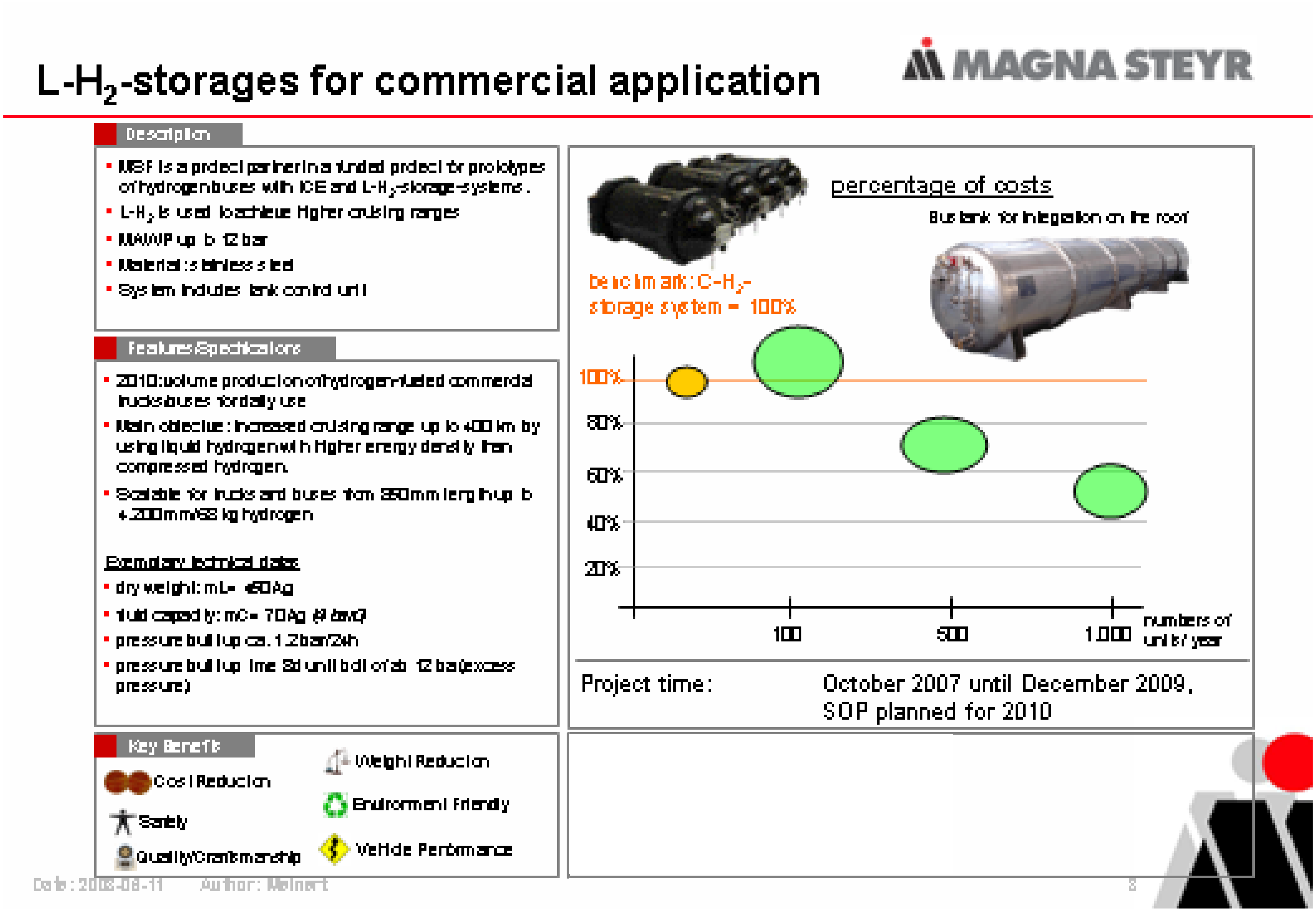
FC Stack Technology

- Daimler/NUCELLSIS 80kW package
- Proton Motor 50kW HD Package
- Nedstack Units 50-150kWe
- Ballard HD-6 (75/150kW)
- UTC 75-170kW
- Nuvera Automotive Stacks 60-137kW

Example of LH2 Storage



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A Visionary Concept?

- Turkey to become the Hydrail innovation center, forming a bridge between European and Developing Markets
  - Turkey has a strong relevant scientific base
    - UNIDO ICHET, MARMARA Research Center, TUBITAK
  - Turkish rail already employs State of the Art Technology
  - Turkey has a very competitive heavy manufacturing industry (steel, electric machinery)
  - Turkey has excellent renewable energy sources which it is developing with its own industry
    - but is not yet fully connected to sell its renewable enregy during peak production periods creating similar porblems as e.g. in Spain
  - Last, not least: Turkey has a huge internal market
    - Regional coheasion
    - Tourist regions
    - International transfer (Syria, Irak, etc.)
- If successful huge international export markets wait including China

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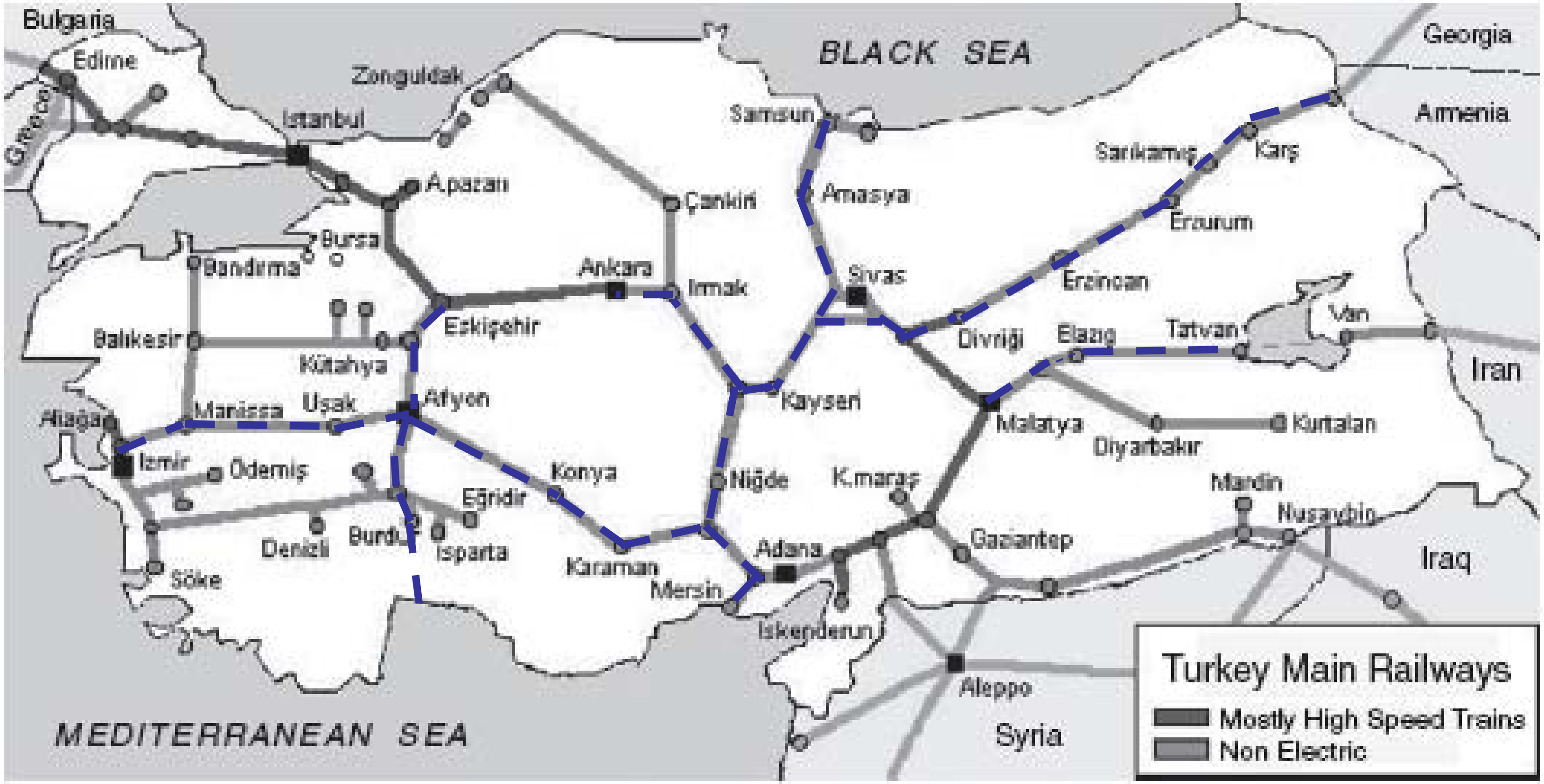
Turkish Hydrail Lines?



Map taken from R. Freeman in EIR, April, 3, 2009

— — Hydrail

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A Multiple Phase Approach

- Phase 1 Feasibility Study (< 2 M€, 18-24 months)
  - Co-operation with UNIDO ICHET, TUBITAK and others
  - Content:
    - Analysis of rail lines (distance, inclination, traffic patterns, typical numbers of railcars)
    - Load simulations using e.g. Advisor
    - Powertrain configurations and refueling needs
    - Packaging studies and concept designs
    - Industry capacity analysis and coalition potentials
    - National and international markets
- Phase 2 Prototype Manufacturing (25 – 60 M€, 24-36 months)
  - Conversion of existing rolling stock to gain operational experience at lowest possible cost/risk
- Phase 3 Full series manufacturing designs and set-up

Conclusion and Outlook

- Conclusion
  - FC powered mass transport is possible for all size classes
  - Durability can be massively improved with smart hybridisation
  - Preliminary calculations show that economics will work in many cases
- Outlook
  - Turkey could become the first Hydrail Hub and a major industrial force in this sector
  - It has all the necessary elements for developing a world leadership position
  - Development could be fast and relatively economical

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THANK YOU

NTDA Energía, S.L..
Ciudad Politécnica de la Innovación
Edificio 8G, Accesso B, 4ª Planta
Campus Universidad Politécnica de Valencia
Camino de Vera S/N
46022 Valencia
Spain
T: 34 963 567755
E: hwancura@ntdaenergia.com

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